EXPLORATION & EXPLOITATION: KNOWLEDGE CREATION IN A BIOTECHNOLOGY FIRM

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Abstract:

The biotechnology industry offers an exciting context to analyze how organizations are able to manage two different but complementary issues: the ability to search for new knowledge –knowledge exploration—and the ability to use existing knowledge—knowledge exploitation. This paper presents a case study of a biotechnology company in the Boston area. The case provides a detailed analysis of the use of problem-solving activities on a collaborative effort between this company and a pharmaceutical company to develop a novel process for developing new drugs. The case investigates how the biotechnology company uses problem-solving activities to balance the ability to explore and exploit knowledge. The main conclusion of this case is that problem- solving activities are being used both to increase the current knowledge base as well as to refine the knowledge base through developing new opportunities for the company. The case also stresses the importance of creating an independent project management team to manage knowledge integration and dissemination.

1. INTRODUCTION

The importance of an organization's ability to adapt and learn has increased with the rapid pace of globalization and technological advancement. There is an "imperative to grow" and this imperative has spurred organizations to pursue ambitious goals of developing new products and markets. At the same time, there is also increasing pressure to improve the productivity of both manufacturing and product development. Organizations need to create new knowledge fast and efficiently: i.e., they need to reduce the expense of developing a new product, while speeding up the process.

This issue is particularly important for the biotechnology and pharmaceutical industries. According to the Tufts Center for the Study of Drug Development, the drug development process takes an average of 15 years to go from basic research to market introduction. Additionally, the development process may require up to 500 million dollars. Studies also indicate that out of 5,000 drug candidates, only five go from research to the clinical stage, and out of those, only one reaches market introduction (Müller, 2002). New drug development is thus very costly and has a very high rate of failure: the percentage of compounds which fail or drop out of the process is over 99% (Cunningham, 2000). To speed up the process of drug discovery, several companies have been trying to accelerate the learning curve that each new development project has to go through. Toward this end, biotechnology companies are investing in two activities: exploring new knowledge by experimenting with the drug development process, and exploiting existing knowledge by incorporating known processes, routines, and technologies into their tool arsenal.

In previous studies, the exploration of new knowledge has been defined as "the pursuit of knowledge of things that might come to be known," whereas exploitation of available knowledge is "the use and development of things already known" (Levinthal and March, 1993: 105). Some researchers refer to exploration versus exploitation as a dichotomous choice (Rothaermel, 2001): If an organization is investing in exploring new knowledge, must it forfeit investment in exploitation of existing knowledge? Are exploration and exploitation mutually exclusive?

This paper presents a case study of a collaborative effort between a biotechnology company and a pharmaceutical company, where the focus is on the analysis of problem-solving activities that are used by the biotechnology company to balance the ability to explore new knowledge and exploit available knowledge. The paper is organized as follows: in the next section, the paper presents a brief overview of the research on exploration versus exploitation of knowledge and the link between this research and the research on organizational learning; the third and fourth sections describe the research methods and the case study; the fifth section presents and discusses the meaning of the results; and the sixth section presents a summary of the results as well as the contributions, limitations and implications for future research.

2. THEORETICAL FRAMEWORK

The study of how organizations learn, the variability of how well they learn, and the factors that improve their learning have been the foci of a considerable body of research (Argote and Epple, 1990; Argote, 1999; Dutton and Thomas, 1984; Levy, 1965; Mukherjee, Lapre, and Wassenhove, 1998; Pisano, 1994, 1996, 1997). Recently,

researchers have been trying to link the process of learning and the development of dynamic capabilities, essentially recasting organizational learning as a set of tradeoffs between March's exploration of new knowledge and exploitation of available knowledge (Dosi and Marengo, 1997; March, 1991; Rothaermel, 2001). The organization may choose to invest in the refinement of an existing technology or on any other activity that is oriented toward increasing efficiency (Dosi and Marengo, 1997), or it may choose to invest in activities that search for novel processes or the discovery of new opportunities.

March (1991) argues that the organizations that engage in exploration to the exclusion of exploitation are likely to be penalized by the experimentation without gaining many of its benefits, whereas the organizations that engage in exploitation to the exclusion of exploration are likely to find themselves trapped in a "suboptimal equilibria" (p. 73). Companies thus face a trade-off between exploration and exploitation: If the company does not reach an appropriate equilibrium between the two ends of the continuum, the company may end up suffering from suboptimization. For example, if a company invests too much in exploring new knowledge, it may sacrifice efficiency gains and thereby relinquish space for the competition. Conversely, if the company invests too much in exploiting old knowledge, its core capabilities may become core rigidities (Leonard-Barton, 1992). In sum, firms face a tradeoff between the creation of new capabilities and the development of current capabilities.

How is this trade-off related to learning strategies? Many authors suggest that learning strategies can be divided into learning *before* doing and learning *by* doing (Pisano, 1997; Argote, 1999). It has been shown that the type of strategy of learning

chosen by an organization is contingent upon the "state of knowledge" on which the organization is based (Pisano, 1994, 1996). If the knowledge needed for developing a market is already mature, the organization will tend to invest more in learning before doing (e.g., the pharmaceutical industry has a large body of chemical knowledge about the compounds that it uses to develop new drugs). By contrast, if the knowledge needed for developing a market is in its infancy and causal associations are not well understood, the organization will typically rely on learning by doing (in the biotechnology industry, there is a much smaller body of existing knowledge upon which the firms can rely, thus they tend to place more emphasis on experimentation) (Pisano, 1994).

Learning before doing can be defined as the processes devoted to improving understanding of aspects involved in the production process before the production process starts (Argote, 1999; Pisano, 1994, 1996, 1997; Vidal and Schilling, 2002). Learning before doing is a learning strategy that enables firms to exploit their existing knowledge base. If the organization has a deeper understanding of the underlying cause and effect relationships behind the problem, then the organization can use its knowledge base to solve potential problems before commencing production.

Learning by doing refers to the process by which an individual or group increases its performance with experience in a task (Arrow, 1962). Learning by doing is required when the organization needs to develop new solutions that are independent of the current state of knowledge (Sitkin et al., 1994). Through learning by doing, the organization will take advantage of the resulting "high-fidelity experimental results" (Pisano, 1997: p. 45).

This paper argues that the choice of learning strategy (*before* doing versus *by* doing) and the choice of balance between exploration and exploitation will be interrelated since both are related to state of existing knowledge and the firm's orientation toward it (Pisano, 1994, 1996, 1997). The problem-solving activities performed by organizations can be classified as focusing on either exploring or exploiting knowledge. Activities that explore new knowledge are more likely to be considered typical of a strategy of learning by doing, and activities that exploit current knowledge are more likely to be considered typical of a strategy of learning before doing.

However, as the nomenclature indicates (learning *before* and *by* doing), the identification of these learning strategies has a hidden assumption that the activities occur in a particular sequence in time. Investment in problem-solving activities that are termed learning *before* doing are assumed to occur at (or prior to) the start of the process. Learning before doing is thus assumed to take place prior to learning by doing. However, as Zollo and Winter (2002) pointed out recently, one should think about the learning process as a cycle: "The knowledge cycle proceeds … from an exploration phase to an exploitation one, potentially feeding back into a new exploration phase" (p. 344). Consistent with Zollo and Winter's arguments, it is argued here that many problem-solving activities occur simultaneously, without sequential constraints. There may be some activities that are more exploitative in the beginning of the process, as well as some explorative activities in the end of the process, and there may be many cycles of iterations between activities at the two ends of the exploration-exploitation continuum.

3. METHODOLOGY

This paper draws on qualitative data collected during a case study of a biotechnology company in the Boston area. Qualitative research is a very useful methodology for exploring new or poorly understood phenomena since it allows us to understand how and why a certain phenomenon occurs (Edmondson, 2002; Eisenhardt, 1989; Yin, 1994). As is customary in field research, the selection of the firm was chosen with respect to my ability to gain in-depth access rather than through a random sampling methodology. Gaining in-depth access can be difficult in any industry, but it is particularly so in the biotechnology industry due to the complexity and secrecy of the technologies involved. There are often issues of confidentiality since projects may deal with drug targets still in development, or waiting for Food and Drug Agency (FDA) approval. Despite these challenges, I managed to develop a relationship with an established Cambridge-based biotechnology company that permitted in-depth examination of several on-going development projects.

The interviews were based on a structured protocol, utilizing a questionnaire that I developed (Appendix 1). The questionnaire was analyzed and commented upon by two researchers who worked in the same field of inquiry. The commentary from these researchers helped focus the content of the questionnaire. Each interview took between sixty and ninety minutes. The questionnaire consisted of open-ended questions, and I followed the protocol for every interview verbatim (Judd, Smith, and Kidder, 1991).

I visited the company several times and interviewed in person the people who agreed to participate. The interviews were taped with permission of the interviewees to provide a complete record of the interviews. The data analysis presented in this study

refers to the interview of five people in this biotechnology company: the Project Manager, the Senior Manager, two middle managers (Manager 1 and Manager 2), and Manager 3, who was a scientist from the pharmaceutical partner (Table 1).

Table 1 and 2 around here

I selected a group in the company that was involved in the early discovery of drug targets. This group would have more information on the use of problem-solving activities since they had already gone through several instances of the development process for which the group was responsible. The most common problem-solving activities addressed by the interviewees are described in Table 2.

I also obtained secondary and archival data from available public records to better understand the process described as well as the technologies involved (Yin, 1994).

4. CASE: PRIMA INC. [1]

The Biotechnology Company Prima Inc. (hereafter Prima), the focus of this study, is an established company located in Cambridge, MA, with more than 2,000 employees. This company uses the latest advances in what has been called the genomics approach for drug discovery[2] (Haseltine, 1998). The genomics approach is based on technologies that permit high-throughput or massively parallel analysis of the structure and the activity of genomes (Cunningham, 2000). Prima's goal is to use its drug discovery platform to enable and accelerate the discovery and development of new, proprietary therapeutic and

[1] This is a pseudonym for the biotechnology company in the Boston area.

diagnostic products capable of addressing diseases at their root causes, rather than simply identifying and treating their symptoms. This company has multiple drug projects in various phases of development, in areas such as inflammation, cardiovascular diseases, oncology, and metabolic diseases. Prima uses advanced technologies for drug discovery that were either developed internally or licensed from other companies. Prima uses extensive alliances with top pharmaceutical companies around the world to finance its investments in its own pipeline of drugs.

5. PROJECT ANALYZED

The project analyzed was the development of a new process for drug development. This project resulted from a collaborative agreement between Prima and an international pharmaceutical company. The agreement specified well-defined milestones for the collaboration, that specified the quantity of targets, vectors, and configured assays, and when they had to be delivered to the pharmaceutical partner. The pharmaceutical company agreed to pay a significant amount of cash up front, which supported Prima's efforts to fulfill its obligation to the pharmaceutical company as well as fund its own internal development pipeline.

Under this collaboration, Prima had a contract to identify 225 novel disease-relevant drug targets in a five-year period. In order to fulfill this obligation, Prima, in agreement with its partner, devised a new process for drug discovery, which differed significantly from the conventional process in use by the bio-pharmaceutical industry.

[2] Genomics refers to the automation of gene sequencing and analysis.

The conventional process is complex and time consuming. It begins with the identification of genes, which when expressed abnormally, result in a particular disease. Then, there is the identification and validation of the proteins (or targets) that different genes produce in different parts of the body. The third step is to identify small molecules that will attach to the target protein and prevent it from causing disease (compound screening and lead optimization). After optimization of the lead, the targets enter into the testing phase. The leads are first tested on animals (pre-clinic), then on humans (phase I, phase II and phase III). Finally, there is the market launch of the drug, when the important issues are the need to find an economically viable way to manufacture the drugs on a large scale and to market them successfully to doctors and patients.

From very early on, Prima intended to use the newest technologies (either internally developed or licensed from other companies) to speed up the drug development process. First it used genetic approaches (positional cloning of disease relevant genes) to identify genes that were the best candidates for drug development. However, when the company moved these genes into the drug discovery pipeline, it realized that there was not enough technology or expertise available (at that point in time) to get these possible drugs targets through the drug development process. Either the function of these genes or the mechanism by which small molecule compounds inhibit these genes was unknown. Prima realized that doing follow-up genetic experiments would lead to greater knowledge about the role of these genes in causing diseases, but not necessarily to the development of a drug. This resulted from the fact that the discovery of a gene that was related to a disease was frequently found to be a non-realistic drug target. Thus, the investment in

research produced interesting biological findings but did not lead to a possible therapeutic drug.

The purpose of the collaboration between Prima and the pharmaceutical company was to try a different approach, a non-conventional model. This approach involves the pre-selection of specific protein targets based on “the historical knowledge that there is only certain classes of proteins that are ‘drugable’” (from an interview at Prima, with Manager 1), i.e., these proteins have particular properties that suggest that small molecules will bind tightly to them. The goal of this collaboration was to identify those "drugable" classes of proteins in the genome that are associated with disease. The two companies further agreed that the validation phase, which is the most time consuming, would be performed in parallel to other phases (Thomke et al., 1998).

5.1. Two Primary Objectives: Development of Bioinformatic Tools and Development of Target Management System

In order to improve its overall drug discovery process and to fulfill its collaborative agreement with the pharmaceutical company, the management team realized that Prima needed to develop several new organizational routines. To develop these new routines several sub-projects took place. Two of these subprojects are examined below.

The first subproject, the development of bioinformatic tools, was a project with a technical background, to create bioinformatic tools to manipulate and process the information being generated in-house. The team of developers was composed of experts in computer science, who had some knowledge in biology. The team of end-users, who

worked together with the developers in this project, was a team of researchers trained in genomic experimentation.

The second subproject, the development of a target management system, was a project with a managerial background: the idea was to create an easy to use computer system that allowed the company's employees to track the targets being discovered in-house. The project management team, an independent team, worked together with the different research teams as well as the managerial team to create the system, and ensure that the employees effectively adopted the system.

5.1.1. The development of bioinformatic tools

One of the most challenging issues that Prima had faced was related to the manipulation and processing of the huge amount of information being generated in-house. To solve this problem, Prima developed in-house "data-mining informatic tools," to analyze the data being generated by laboratory experimentation.

The description of the process of development provides an interesting example of how the different problem-solving activities are used at Prima. An overview of the development process is presented in Figure 1.

Figure 1 around here

Since the amount of data being generated by the genomics experiments was enormous, and there were problems with the "physical manipulation and processing of

the data," (Manager 2) the management at Prima identified a specific problem: the need for developing bioinformatic tools to conduct data mining.

Through planning meetings and informal information sharing (both internal and external), Prima started to develop a computer algorithm to process the data generated by the experiments. After the initial development, the developers (information system specialists, with some expertise in biology) and users (scientists conducting the genomic experiments) interacted through prototype testing. With the use of prototype testing, the users were able to specify all the variables that they would use in their daily job, which created "query abilities" that were not in place in the first prototype (Manager 1).

Even with the creation of different levels of queries, another problem was identified: the need to find the same genes in other species; "to find models in rats, we had to go to another program and do the query again, a process that took two to three hours" (Manager 1). After another interaction with the users and a week of development, the developers improved the computer algorithm to permit the users to perform all the queries as well as to find models in other species in fifteen seconds. This development permitted a gain of more than two hours in processing that information.

To run an algorithm for data mining, Prima first had to create a master database. Prima had developed its own proprietary database. To complement this database, Prima used a public database available from the National Institute of Health (NIH), a database that has information from all the research being funded by the U.S. government. To further complement this database and due to some business pressure, Prima decided to license a proprietary database used in the biotechnology industry. The development of

this database shows an example of exploitation of old knowledge: Prima is using knowledge already available internally and externally to search for new targets.

Since the developers were the only ones in the company who knew how to operate the algorithm, there was a need to standardize the algorithm so that the ultimate users, the scientists, could use the algorithm by themselves. "If the developers were killed in an accident, no one would be able to run [the algorithm]. We needed to invest in creating a more robust program," that every one could run (Manager 1). Prima management decided to invest more resources in the development of a new algorithm, but instead of "just" improving the algorithm, the developers decided to incorporate an innovation: a protein-centered algorithm. The first data-mining algorithm was gene centered, but "one gene can produce more than one protein" (Manager 1). Therefore, the developers decided to create a protein-centered algorithm, in order "to be more comprehensive" (Manager 1). The users were against this path since they believed it would be very difficult to create a reliable protein-centered database. The developers did not listen to the users, however, and finished the protein-centered algorithm. Unfortunately, as had been predicted by the users, the protein-centered algorith turned out to not work as well as the gene-centered algorithm.

5.1.2. The development of a system to manage targets

Since there were several targets being discovered and entering the pipeline, and since Prima had a contractual timeline to deliver targets to the partner pharmaceutical company as well as to other independent partners, Prima had to manage the targets carefully. There was a need to find a way to integrate the data, communicate the data, and

receive input on the data when it was appropriated (Manager 2). Figure 2 presents an overview of the development of the system to manage targets at Prima.

Figure 2 around here

To find a system to track these targets, Prima's management went through several brainstorming and planning meetings with different groups in the company as well as informal exchange of internal and external information. The solution developed was to create a web system to track its targets, which satisfied certain characteristics established over the brainstorming and planning meetings. To create the system, they licensed software. After a few prototype runs, they implemented the system, and used on-the-job training for the system. Prima tried to "put a system in place that would enable everybody in the organization to be more aware of the information, so that multiple people could look at the information at the same time" (Senior Management). The target management system was available to all Prima's employees, which allowed anyone to track down where the target was in the drug discovery process.

Through planning meetings and information sharing, the project management team found out that the system was not working since the ultimate users, the scientists, were not complying with the system. To solve this problem, the project management team went over another round of brainstorming and planning meetings and internal informal information-sharing. The solution created by the project management team was a priority system to accompany the system to manage targets. The groups were required

to give information about the target in order to move it forward in the pipeline – i.e., “it would become a gateway for getting things done” (Project Manager).

Initially, this system did not work because some people would send identical information about one particular target from a previous week in order to bypass the gateway. The project management team solved this problem by designating a team member to attend the research group meetings and make sure they knew exactly where the target was in the process. While doing this, the project management team was able to show the importance of the firm knowing the whereabouts of each target: "We have a team that goes around the company to make sure that groups A, B and C are talking to each other and reassuring that the groups are not duplicating efforts" (Manager 1).

The project management team is seen as completely independent from any research team, and this breaks down some barriers that occur when a project is fruit of the work of several teams: “it is better to have someone else delivering an idea, so that it is not so-and-so’s idea, but it is an idea that the whole project will benefit from it”(Senior Manager). Even though, the project management team was not producing knowledge per se, this team was viewed as a crucial part of the company since it managed the knowledge being created by the different research teams. Prima’s investment in an independent project management team had the effect of accumulating the dispersed knowledge being generated within the company. The storage of the knowledge in a web system allowed the knowledge to be easily accessed throughout the company, permitting a prompt diffusion of this knowledge throughout the company. This example also shows

that Prima's project management team was an effective mechanism for producing internal spillover effects, while reducing external spillover effects.

5.2 Exploration and Exploitation of Knowledge

Due to the strict deadlines that Prima had to follow for the collaboration agreement with the pharmaceutical company, Prima used all the available activities to improve the learning process (Senior Manager). Prima used several problem-solving activities to manage the trade-off between exploiting existing knowledge and exploring new knowledge (i.e., becoming more efficient and finding new possibilities).

Figure 3, for the development of bioinformatic tools, and Figure 4, for the development of a system to manage targets, summarize how the different problem-solving activities used by Prima are related to the exploration versus exploitation trade-off as well as to the timing that each took place. The first stage presented in each figure represents the time when the need for the subproject was acknowledged, and at each stage of the development process a new cycle of problem solving activities takes place.

Figures 3 and 4 around here

As can been seen in both figures, in each phase of the two development processes described in the previous sections, the problem solving activities are both related to exploring new knowledge (e.g., experimentation in Figure 3; and brainstorming meeting in Figure 4), as well as to exploiting available knowledge (e.g., licensing reagents in Figure 3, and planning meeting in Figure 4).

Several problem-solving activities migrate in the continuum from exploration to exploitation of knowledge. Examples in Figure 3 include the planning meetings and prototype testing. For the planning meetings, the migration may be explained by the fact that early on in the development process the teams do not have a clear picture and/or enough information available to use in planning the process. As the process evolved, the teams are able to collect more information about it, and use this information in the meetings. The same can be said about prototype testing: the first prototype testing had a very exploratory nature, since the computer algorithm being developed was starting to take form, and as the development process evolves the new prototype testing uses more available knowledge. In Figure 4, the development of the system to manage targets, prototype testing is also an example of a problem-solving activity that migrates from exploration of knowledge to exploitation of knowledge as the process evolves.

Both Figures 3 and 4 show that through the two development processes, even in the beginning of each developmental stage, some problem-solving activities are oriented more towards the exploration end of the continuum, yet there are other problem-solving activities more related to exploitation of available knowledge. These two figures also indicate that the problem solving activities occurred in a cyclic way: they began with exploring new knowledge and move on to the exploitation of the knowledge newly developed.

From the two examples from Prima, we can see that the different problem-solving activities are used both to increase Prima's current knowledge base as well as to augment this knowledge base through developing “new opportunities.” The form in which these

activities are used shows that, instead of making a dichotomous choice between exploring versus exploiting, Prima used multiple activities to balance exploration and exploitation. There are activities that lie at the ends of this continuum, and these are easy to identify and to manage. For example, at the exploration end, the first laboratory experiment for a target would be the exploration of totally new knowledge; Prima would be pursuing the "knowledge of things that might come to be known" (Levinthal and March, 1983). At the exploitation end, when Prima licenses other companies' technology or products, it is exploiting "things already known" (Levinthal and March, 1983). However there are also several activities that do not lie at either end of the continuum. For example, prototype testing, planning meetings and sharing information contribute to both exploration and exploitation.

Therefore, to focus on exploration or exploitation as an either/or choice may be misleading. The problem-solving activities are intertwined and build on each other. Results from experiments need to be shared and discussed with other groups in order to make sense of the results. In this sense, it is what Nonaka (1994) refers as “organizational knowledge creation” (p. 14): there must be a continuous cycle of socialization, articulation, combination, and internalization of the knowledge. Instead of thinking of this process as a sequential one, we need to think of it as having multiple parallel steps.

6. DISCUSSION

Prima’s new process for drug discovery has everything it needs to be successful. There is a good flow of communication between the two companies, and the project milestones have been met so far. However, a concrete measure of success is still missing

and will have to wait until the first drug developed through this process reaches the market.

In the quest for improving productivity, information is being generated at a very fast pace. The ability to manage all of this information is a critical investment that this company has been making in order to access the information in real time. Knowledge developed from successful as well as failed classes of proteins is kept in a "library" of in-house knowledge. This was felt to be an important asset to the company, and therefore the company was willing to devote time and investment to this potential asset.

The case study presented here demonstrated that the problem-solving activities used by Prima are employed to increase Prima's ability to search for new knowledge (explore), through activities like experimentation, brainstorming meetings, planning meetings, and prototype testing. These problem-solving activities are also employed to increase Prima's ability to use available knowledge (exploit), through activities like licensing reagents and software, training, planning meetings, information sharing (internal and external) and prototype testing.

The results also indicate that these activities occur simultaneously. The timing for these activities to take place is not related to a temporal issue (before or during the process), instead the problem-solving activities can happen in the beginning of the process, or during the process, or in the end of the process.

The academic contribution of this study is to serve as an analysis of problem-solving activities and their relationship to exploration and exploitation. In this case, I analyzed how the problem-solving activities are continually interacting and adjusting.

With a dynamic use of these activities, Prima has been able to meet the rigid milestones defined by the collaborative contract. It seems that the use of project management has been crucial to keep the cycle of knowledge rotating.

For practitioners, it shows the importance of using different activities to develop an internal knowledge base. Organizations cannot possibly invest in developing all knowledge internally. Therefore, they have to create effective mechanisms to gather knowledge from the environment as well as the ability to use this knowledge. It also shows that the use of knowledge management for the organization as a whole will pay off in the end.

7. Limitations and Future Research:

The limitation of this study is that since the results come from a single firm case study, there is the issue of generalizability of the findings. Are the problem-solving activities used in other companies in this industry (or other industries) similar? Do other companies use these activities for the same purposes in terms of exploration and exploitation of knowledge? Future research should analyze other industries to investigate how problem-solving activities are different across industries, and how they are used to balance the exploration and exploitation trade-off. The pace of technological change, competitive intensity, and the state of the knowledge base may all influence the use of different problem-solving activities.

Interesting questions come out of this case study: Do activities at different ends of the exploration-exploitation continuum require different management techniques? What if there are some clusters of activities, and these clusters move around the space of

exploration-exploitation? Are some combinations of activities better than others? This project was the result of an ongoing collaborative agreement between a biotechnology and a pharmaceutical company that permitted us to examine what activities the firm was actually engaging in -- how these problem-solving activities actually helped the collaborative agreement remains unknown.

Appendix 4.1: Protocol for Interview of Biotechnology Company

I am here today to talk about a specific project. The objective of this interview is to gather data for a study of how people solve problems during product development. The objective of this interview is to collect data on the learning processes that the organizations go through in new product development projects.

Description of the project: I will ask you few general questions for you to describe me one project that we are going to focus throughout this interview:

1. What was the project? Characterize the type of product or technology being developed:
2. Here is a typical model of drug development project (refer to page 3). Did this project follow the usual drug development process, if not, which phases were condensed or postponed:
3. How long did the project implementation take for each development stages?
4. How successful was the implementation project: refer to page 4, for performance measures.

Problem solving: Now, I will ask you several questions related to the problem solving activities during the project that you've just described. Show

1. Describe the most significant challenge during the project and at which stage?
2. How was it solved?
3. Describe another one… (at least 3 problem solving instances, refer to page 5 for possible ways to solve the problem or not)
4. Back up questions: **What type of knowledge was needed, new or already available at the company?** Easily accessible? Did you hire new employee or consultants to have the project done? Where and how did you find them? Did you run any type of seminar (i.e., training, brainstorming, etc) with the project group and/or other groups (internally and externally)? How many meetings among the project leaders? With the groups involved?
5. Did you hire consultants to have the project done? What was the type of intervention done by the consultants: training employees in a new technique, or solving a problem? When are you using consultants for new knowledge, what are your concerns?
6. **How successful was the project:** What metrics of performance did your company use?

Thank you for your time, my interview is done. Is there anything else related to this project that you would think would help me better understand the learning processes involved in it?

As soon as I have a draft of my research results, I will be glad to share the results with you.

Once again, thank you very much.

1. How does the use of the learning before doing activities help the project performance?

Activity	Benefits of doing it	Costs of doing it
Simulation		
Prototype testing		
Laboratory experimentation		
Shared Information (in-house)		
Shared information (outside)		
Training		
Brainstorming		
Planning meetings		
Licensing product		
Licensing technology		
Hiring new people		
Consultants: training		
Consultants: solve a problem		
Others:		

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Table 1: People interviewed at the Biotechnology Company

Person	Function
Project Manager	Program Manager, Knowledge management, tracking system, milestones management
Senior Manager	Vice president, early discovery team, interacting with managers from other groups
Manager 1	Director, Senior scientist, management of a subgroup of the early discovery team
Manager 2	Senior scientist 2, management of a subgroup of the early discovery team
Manager 3	Senior scientist from the pharmaceutical partner, working at Prima

Table 2: The problem solving activities used and the acronym used in Figure 1 and 2

Activity	Acronym	Definition used when needed
Prototype testing	PT	Use of prototypes (machine, molecules, etc.)
Laboratory experiment	Exp	Real life experiments
Informal Information Sharing (internally)	IIS	Use of knowledge developed by teams inside the organization (both formal and informal)
Informal Information Sharing (externally)	IES	Use of knowledge of external personnel, in an informal way.
Training	T	Before or during the project training sessions, for either a technique or the use of a technology, for example.
Brainstorming	BM	A team technique to generate creative ideas on a particular subject
Planning meetings	PM	Meeting to plan and discuss the evolution of the project
Licensing product	LP	Need to license a product to continue the project
Licensing technology	LT	Need to license a technology to continue the project
Hiring new people	H	Need to hire new people, either because they lack the expertise or because the project got too big.
Consultants: training	CT	An outside person that is hired to train the company's employee in either a technique, or a technology (e.g., academic professors that come to teach the company's research on an experiment).
Consultants: solve a problem	CP	An outside person that is hired to fix a problem (e.g., an employee from a consultant company that is hired to fix a problem).

Figure 1: An overview of the development of the bioinformatic tools at Prima

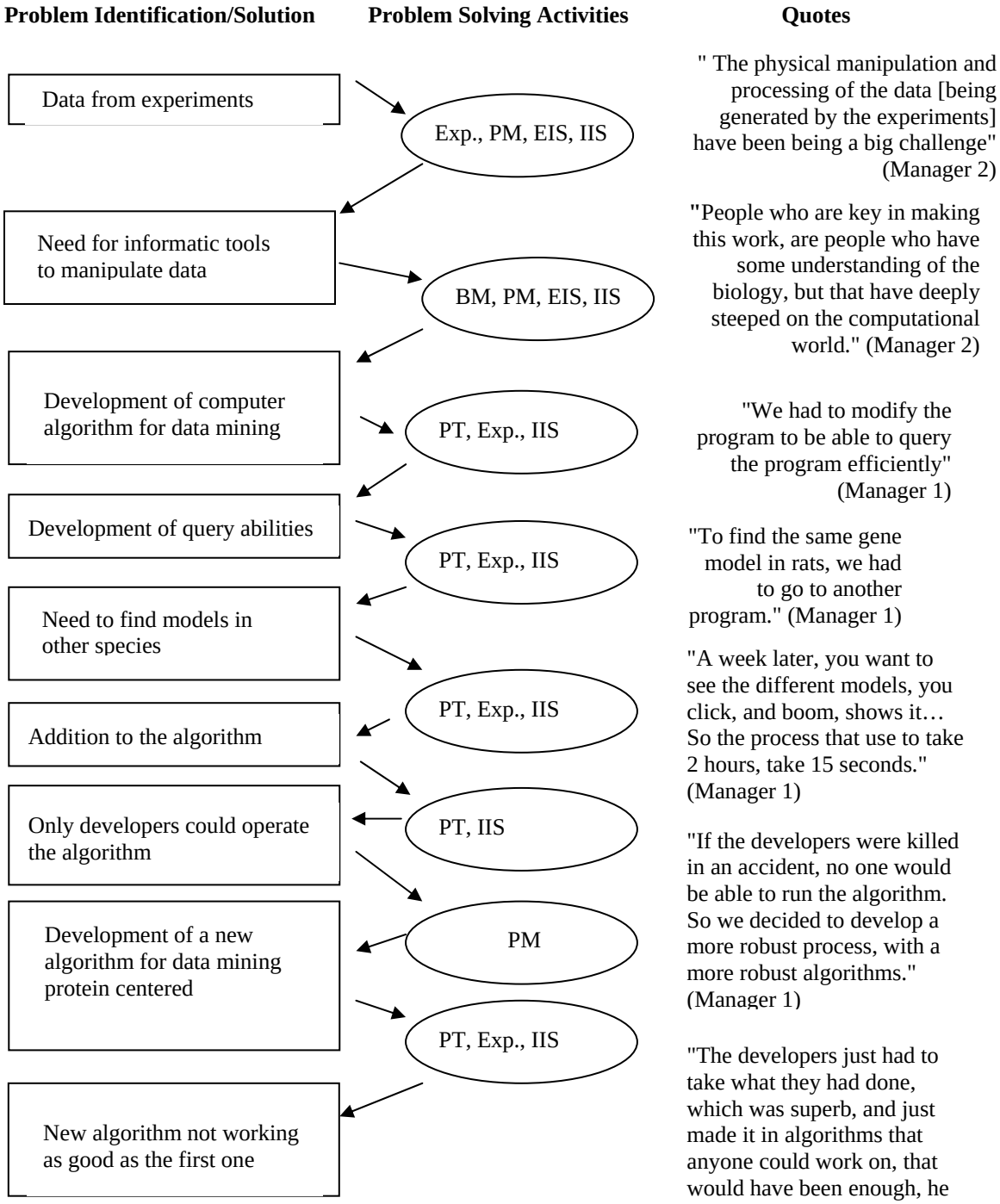

Figure 2: An overview of the development of the system to manage target

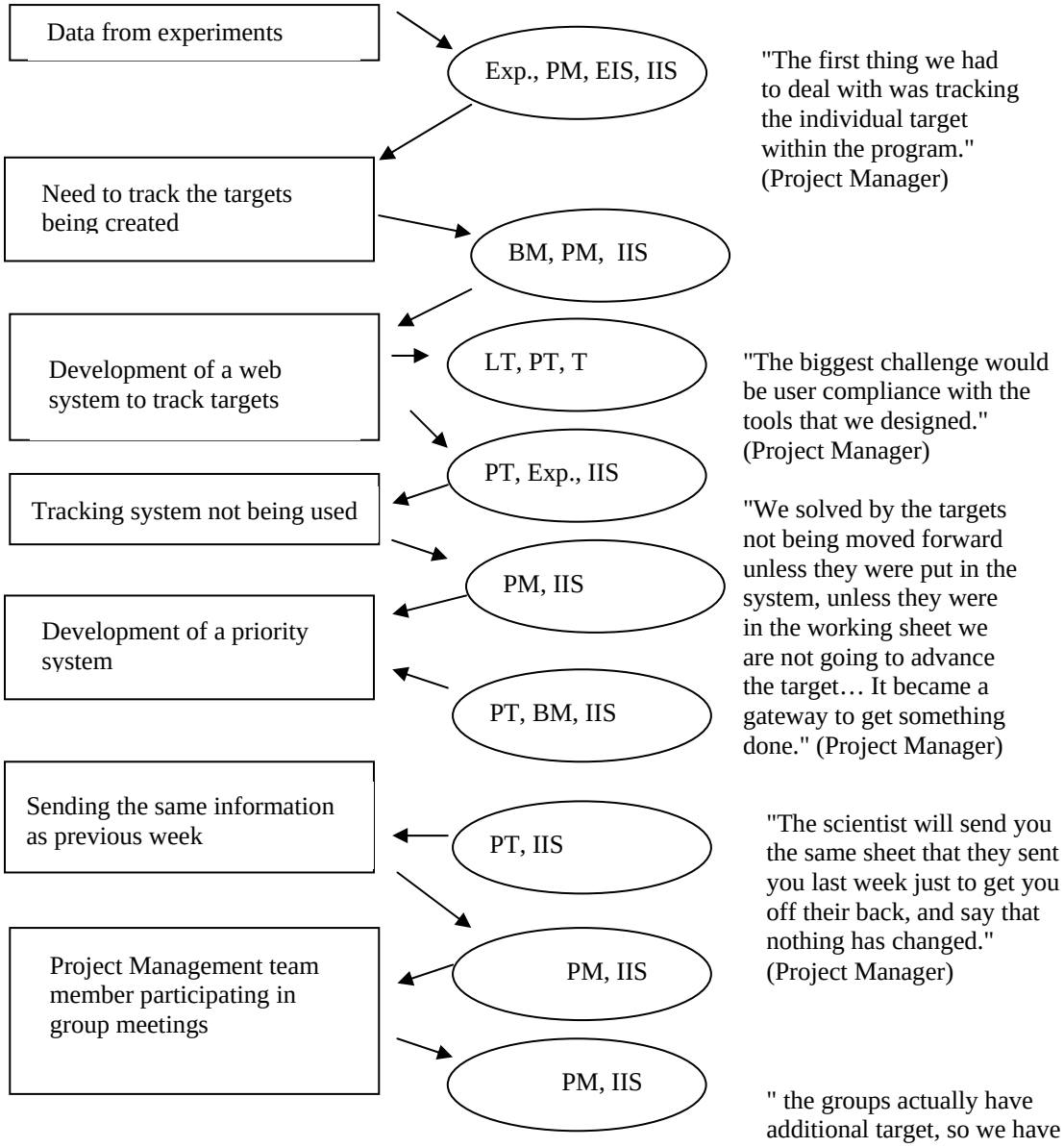

Figure 3. The development of bioinformatic tools and the timing of the problem solving activities

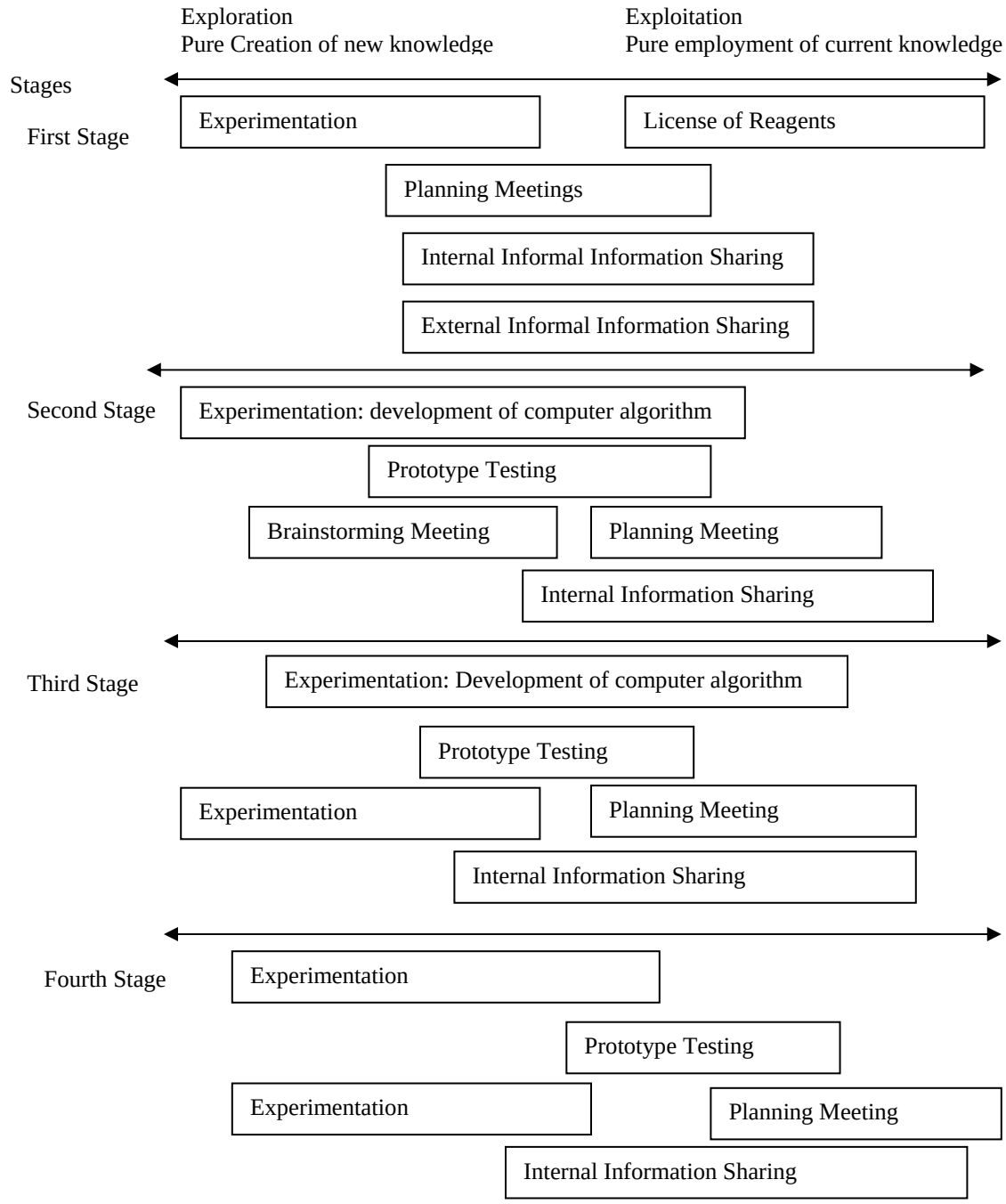

Figure 4. The development of the system to manage targets and the timing of the problem solving activities