OPTIMIZATION OF MECHANICAL PROJECTS AS A LEARNING PROCESS

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Abstract. *The objective of this article is to analyze the problem of the learning process in manufactured product projects. All of the current product development models emphasize the necessity of the learning process in projects, but none of them propose how to implement it. To improve the learning capacity, by taking advantage of past experiences and lessons result in an increase of the efficiency and of the quality of the project. The development of products, contemporary, is an intensive process of knowledge that, according to Pahl and Beitz, results from alternating between the work and decision steps, or that is to say, could be understood as a transformation process of information into knowledge. The graphic structure of the "development funnel", proposed by Wheelwright and Clark, illustrates a situation in which the initial phases of a project characterize themselves by the high degree of uncertainty and by the large quantity of conceptual options. In this way, the results presented prove the necessity of learning support tools directed to project specialists to assist in the individual learning and in the transfer of knowledge. It also shows, that the lack of learning among the different projects demand an approach orientated to the cognitive tasks of the project designers, principally during the initial phases of the project process.*

Keywords*: project process, product development, cognition, experience.*

1. INTRODUCTION

The last two decades of the XX century made evident the importance of management for the competitiveness of organizations. With a relatively calm environment until then, principally in the 1980's, the North American and European companies, suffocated by the competition of the Japanese industry, noticed that the competitive advantage resulted, in great part, from the method by which their products were developed and perfected. The product development (PD) consists of a set of activities geared to transform the necessities of the market into a product. Clark and Fujimoto (1991) defined PD as a transformation of the market opportunities data into information to produce a commercial product.

It is through the activities of product development, a business process, that an organization creates more competitive products in tune with the necessities of society. The PD evolved from a process of sequential development, of a traditional view, at the beginning, to a model of integrated product development with ample use of simultaneous engineering (Rozenfeld et al., 2006). Today, the product development process (PDP) plays a more strategic role in the organization, being treated as a broad business process, aligned with the strategic planning that encompasses the entire life cycle of the product. The contemporary PDP is, in essence, a multi- discipline and inter-discipline process that requires the participation of all areas of the organization, and the activities carried out depend on various inter-related areas.

It is undeniable that the studies carried out in the area of PDP have reached a high level in terms management structure and models. However, the subject of learning inside of PDP did not reach the same knowledge level as we find in the current PDP models. Although diverse studies already have been published in the area with the purpose to structuralize the learning process, significant gaps still exist. This is due to, in a certain way, more to the lack of relative studies about learning than to PDP. The fact is aggravated by the fact that the carried out studies are still concentrated on the organizational and management levels. Few studies have been carried out taking into account the micro-processes that support the learning, specifically when analyzed under the perspective of the PDP.

All current models of PD emphasize the necessity of the learning process and such models concentrate on the scope of macro-processes of the organization, neglecting the central process that leads to learning, the micro-processes of transference of the individual learning to the collective one, either in an organizational or group level. One argues that the project of a product, mechanical projects in a general way, can also be optimized by means of the learning and that such process is currently relegated to a secondary function.

The lack of learning in projects manifests itself initially on an individual level and, to fill this lack, it is necessary first to resolve the question of learning on an individual level. In this way, this study of PDP shows the necessity of a tool of support to learning, directed to project specialists to assist in the individual learning and the transference of this knowledge. It also shows that the lack of learning, that is, the crossed learning among the diverse projects, demands an approach geared to the cognitive tasks of the specialists for which it is directed.

The complex nature of PDP is also one of the factors that hinders the learning. About the complexity of the work and cognitive aspects, Marmaras and Pavard (1999) proposed an approach orientated to the problem, that is, the real problems and the difficulties encountered by the people who solve the problems and guide the project's system. The authors define the term "complex cognitive tasks" by means of examples such as traffic control, medical diagnosis, the project, production management and planning, and computer programming. These cited activities possess common characteristics, on the cognitive level as well as on the environmental level where the activity is inserted. The authors affirm that the "difficulties in the complex cognitive tasks are due to both the cognitive process complexity necessary to the execution of the tasks as well as to the complexity of the environment inside of which and for which they are executed". The PDP is a complex process that relates to all the areas of the organization and that involves the cognition of the people and the work environment, and the barriers to learning fundamentally arise from this complexity.

2. THE PRODUCT DEVELOPMENT PROCESS AND LEARNING

Diverse theoreticians have proposed various definitions in relation to organizational learning, and the majority link them to the acquisition of knowledge and to continuous improvement. The organizational learning can be defined as a process of detection and correction of errors (Argyris apud Garvin, 2001), like a capacity of self development and of self transformation (Starkey, 1992) or as a capacity to acquire knowledge through experience (Shaw and Perkins, 1994). The definition of Garvin (2001) is more complete, since it defines in a more concrete way the organization that learns as the one that "makes available the abilities to create, to acquire and to transfer knowledge, and is capable of modifying its behavior, in a way to reflect the new knowledge and ideas".

Some theoreticians in the learning area differentiate the learning organization (LO) from organizational learning (OL). However, authors on PDP, as Alliprandini (1999), don't make distinctions between LO and OL, they mention that "OL is a characteristic of LO (an organization that learns)" and treats the subject inside of a single context. In the same line of reasoning, Rozenfeld et al. (2006) treats the subject of OL as a metaphor and inserts as a central point of learning, the professional in the development of his individual competencies. The authors define competency as a set of knowledge that involves abilities and attitudes, a formed capacity that is developed by the individual from the practical experience in the solution of problems. The organizations with excellence in PD all present a standard of coherence and consistency during the process in terms of strategy, culture, organizational structure, systemized activities and, also, the learning mechanisms.

Pahl et al. (2005) do not make direct reference to OL in their work, treating the subject of learning indirectly by means of the designer's individual dimension. The designer, in the product project, occupies a relevant and responsible position in the search for the solution and the development of a product, as much as in the individual as well as in team work, where "his ideas, knowledge and talent determine the technical, economic and ecological characteristics of the product before the manufacturer and the user". The learning is treated as an inherent characteristic, where the responsibility belongs to the designer in view of his knowledge, something implicit in terms of the process. To develop and to design are a multifaceted activity (Dixon, 1966 apud Pahl et al., 2005; Penny, 1970 apud Pahl et al., 2005) that can be analyzed under three perspectives: of the psychology of work, methodological and organizational. From the point of view of work psychology, to design is an intellectual, creative activity, that requires a safe base of knowledge and experience in the areas of exact sciences, of materials, and of project and production technologies. From the methodological point of view, to design is a process of optimization with predetermined and conditional objectives with conflicting parts. From the organizational point of view, the project participates in a significant way in the life cycle of the product, that starts from the demand of the market or the product planning and finishes in its recycling or its discard.

2.1. Learning on PDP Models

Inside of this process, Wheelwright and Clark (1992) proposed the model of development in "funnel" (Fig. 1), in the end of which the learning after-project occupies a prominent position. It is about one of the first models of PD that proves the importance of learning and that shows that the gains of a project are not limited to the financial return. The model of learning of Wheelwright and Clark (1992) starts by the concept that the project is the result of a broader process and that the execution not only creates learning opportunities, but also is a key element in the building process of the knowledge of the organization. The knowledge acquired through the project groups can and should be captured, retained and reutilized. The importance of the model of Wheelwright and Clark (1992) is to explain and to reveal strategically the process of learning, post-project, and continuous feedback at the organizational level.

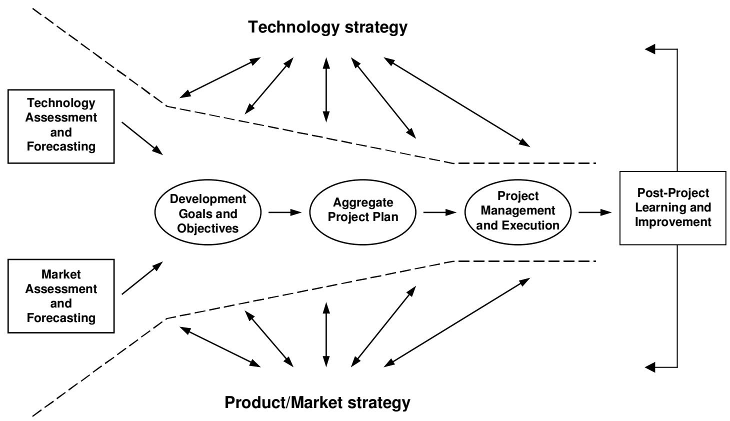

Figure 1. Development funnel (Wheelwright and Clark, 1992)

The reference model of the PDP proposed by Rozenfeld et al. (2006) is an evolution of the general model developed by the PDPNet community and is directed to the segments of durable goods and equipment. It is about a model focused on mechanical manufacturing technologies. This model of reference structures a set of generic activities to be executed between the phases of the planning of the projects and the launching of the products (Fig. 2).

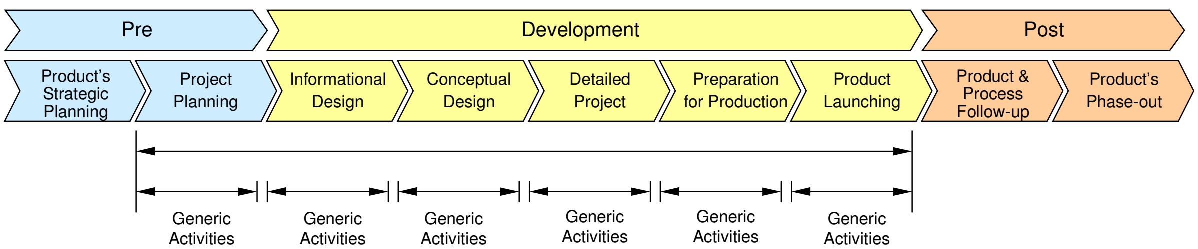

Figure 2. The phases of the reference model, each one with the generic activity (Rozenfeld et al., 2006)

All the generic activities of the presented phases finish with the register and the documentation of the decisions taken and the lessons learned during the phases (Fig. 3). The theoretical contribution of the model in respect to learning is the detailing inside of the macro-phases, not only at the end, as it is proposed in the development funnel of Wheelwright and Clark (1992). The model of reference of Rozenfeld et al. (2006) deepens the learning process, inserting it as an activity internal to the phases, and not only limited to the strategic context of the funnel model.

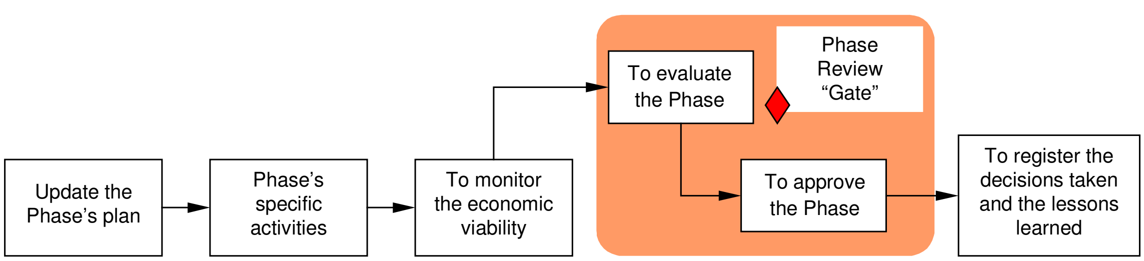

Figure 3. The generic activity (Rozenfeld et al., 2006)

The last event of the generic activity formalizes the moment of the documentation, the register of the decisions and the lessons learned. This event is related to the continuous improvement of the PDP. About this process of learning, Rozenfeld et al. (2006) affirm that the register of the learned lessons must be systemized, since the documentation cannot be an informal and non-structuralized activity, in a way that guarantees that the critical analysis is always carried out. The authors alert, that even though, the systematization is simple, there is complexity in relation to the required analyses, suggesting a stratification by topics, like technical aspects of the product, the production process and management of the project, among others. The model does not consider neither a method nor a system for the accomplishment of this activity and suggests that the task to classify the information and to make an association with the product or process object can be done in accordance with the level of formal procedures of the company.

The new approaches for the integrated development of products such as Lean, Design for Six Sigma, Maturity Model and Product Life Cycle Management present characteristics as (a) simplification of the formalization through team work with the use of more sophisticated computational tools; (b) emphasis on the learning; (c) adoption of the concept of maturity levels; and (d) adoption of the concept of product life cycle management (Rozenfeld et al., 2006).

Although the presented models mention and emphasize the importance of learning, one still needs to better specify how one proceeds to systemize and implement this learning inside of PDP.

3. THE LACK OF LEARNING IN THE CROSS PRODUCT DEVELOPMENT

The contemporary PDP is a creative and intensive process of the application of knowledge. As Pahl et al. (2005) mention, the main mission of the designer, the term that the author uses as a synonym to project engineer and development engineer, is to solve the technical problems. The designer works based on his knowledge of the natural sciences and engineering, taking into account the material, technical and economic requirements, and the legal and environmental restrictions imposed by society. The great diversity of tasks and objectives demand of the designer a set of multipurpose abilities, that includes the knowledge of project, of tools, of work methodology, among others.

Pahl et al. (2005) define the project methodology as “a planned procedure [...] in the development and in the project of technical systems, that resulted from knowledge in the area of the project science and of the cognitive psychology and also from the experience with different applications”. Rozenfeld et al. (2006) define it as being a sequence of stages and rational activities to develop a product, and affirm that the proposal of project methodologies was an important landmark for PD.

A study was carried out in a company from the electrical appliance sector, a Brazilian subsidiary of a North American multinational, one of the biggest world-wide manufacturers of white line products, showed in the adopted PDP model the macro-phases shown in Fig. 4.

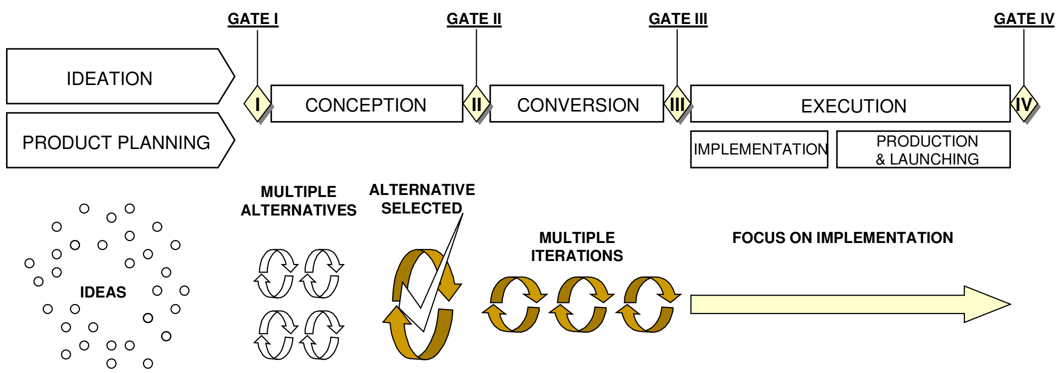

Figure 4. The PDP macrophases from idea generation to product launching

It can be observed that the PDP model of the organization studied does not have a formalized and integrated learning process as exists in current models. The initial phases of the project of the organization are characterized by the high degree of uncertainty and by a large quantity of conceptual options. The phase of determining the concept of the product, the conception phase, is the one that takes the longest. In this phase, diverse experimental tests are carried out and repeated exhaustingly until one reaches a viable solution both technically and economically. The initial phases are characterized by the iterative cycles of Designing/Constructing/Testing/Optimizing, typical of this phase of development, with constant alterations in the project.

However, the choice of the solution that presents itself as the most adequate and viable to advance to the following phases has always been difficult, since a mistaken choice can cause delay in the launch of the project or even provoke its cancellation. In both situations, there is loss of competitiveness for the company in an irreparable form.

For the project teams, it does not go unnoticed the waste of time that occurs during the initial development. When treading the same path covered previously in the search for a solution from ground zero, the repetition of the same errors, the search for a new solution, the delays in the development schedule, the reduction of the development time in favor of maintaining the launch date, the losses in quality due to the reduction in the development time, culminate, to a product already in the consumer’s house, with predictable or unexpected imperfections appearing. This cycle, many times, comes back to repeat itself in other projects.

All the projects start with the formation of groups of simultaneous engineering, as can be observed in the PDP model unfolded in activities (Fig. 5). To develop products it is required information and abilities of people from all areas of the organization. Figure 5 also shows that the activity of conception of the product (the activity number 2) plays a fundamental role, if not the most relevant, since it decisively intervenes with all the other activities of the process. The activity of product project possesses a wide diversity of technical barriers, that start appearing in the day to day, as the experiments are being carried out. These problems are overcome by the specialists, one by one, until they reach an adequate configuration. This phase has innumerable iterative cycles of optimization, characterized by the wealth of cases, that possess immeasurable value when viewed as a learning process. They are rich experiences, many involving creative, positive and negative solutions, that tend to be lost with time.

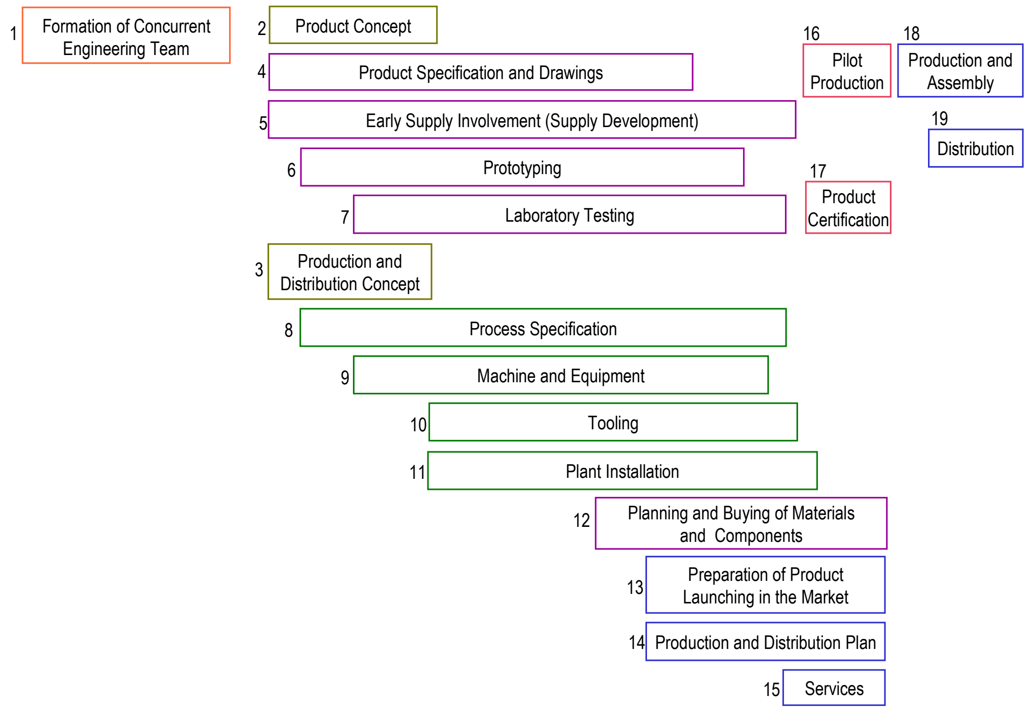

Figure 5. The macrophases deployed in specific activities

To find a way of assisting in the cognitive work of the specialists from the experience assimilated from other specialists becomes a decisive factor to more easily transpose an obstacle that may appear in the future. The lack of learning shows the necessity of an orientated approach to the problem in assisting the cognitive tasks of the specialists, mainly during the initial stages of the project, the creation phase.

4. PRODUCT DEVELOPMENT AS AN INFORMATION TRANSFORMATION PROCESS

According to Pahl and Beitz (apud Back and Forcellini, 1997), the product development process results from alternating decision and work steps, and can be understood as a transformation process of information. At each step of the work there is an associated series of information.

Before, it is necessary to distinguish the terms for the continuation of this work. Frequently, “data” and “information” have been used as synonyms, as well as “information” and “knowledge”. Data is the crude raw material, without meaning, that composes the information. It is an element, or group of elements, neutral and non-political. “Data are a set of distinct and objective facts, relative to events” (Davenport and Prusak, 1998).

Now, information is processed data, organized with the objective to supply some specific problem. The data are transformed into information, adding value (Davenport and Prusak, 1998). The information, therefore, differs from the data, since it carries some specific objective. Information can be defined as “data endowed with purpose and relevance” (Drucker, 1992), used to provide “a new point of view for interpretation of events or objects” (Nonaka and Takeuchi, 1997), or “to exert some impact on your judgment and behavior” (Davenport and Prusak, 1998), or still to turn “meanings visible, that before were invisible, or to shed light on unexpected connections” (Nonaka and Takeuchi, 1997).

In the same way that the data are the raw material of the information, the information is the fundamental compound for the creation of knowledge. The information is a means or way to extract and to construct the knowledge (Nonaka and Takeuchi, 1997). The knowledge is something that is constructed, or formed, from the use of the information; and, still, information enriched by means of interpretation, analysis and contextualization (Duffy, 2000).

Knowledge is a mixture of various elements, at the same time fluid and structuralized, intuitive and difficult of being defined; it involves experience, values and insights, providing a structure for the evaluation and the incorporation of new experiences and information. In the organizations, it is embedded not only in documents or repositories, but also in routines, processes, practices and organizational norms (Davenport and Prusak, 1998).

One cannot precisely define the difference between knowledge and information, since a precise limit separating these two elements does not exist. There is, thus, a difficulty of practical order to distinguish the knowledge from the information, since at a specific moment the information is transformed into knowledge. This transformation depends on the receiver. It could be, to some, only information and, to others, valuable knowledge. For this work, explicit knowledge begins to be information, when, at every information transformation that is carried out, a value is added.

The activity to plan and to project is understood as conversion of the information. Each conversion of information must be accompanied by an increase of value for the intended improvement. To convert the information in the project means that information was obtained, processed and communicated (Pahl et al., 2005).

The processing of information occurs through the analysis of the information, synthesis of reasoning and combinations, detailing of solution concepts, calculations, tests, execution and correction of sketches, basic projects and drawings, and evaluation of solutions. The communication of information occurs through the registration of the ideas in sketches, drawings and tables, test reports, use and assembly instruction and work plan (Pahl et al., 2005).

Dörner (1979 apud Pahl et al., 2005) describes the solution of a problem as a processing of information (Fig. 6). A process of information, iterative, to approach the solution step by step, continuously reaching a higher level from the previous one.

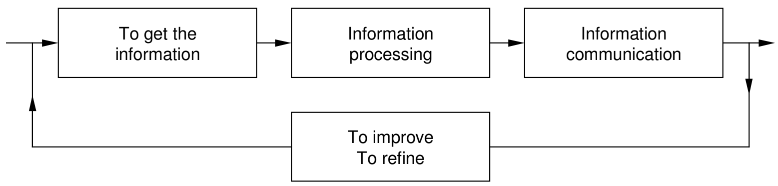

Figure 6. Information's conversion with iterative net (Pahl et al., 2005)

Pahl et al. (2005) call attention to the importance of the cognitive dimension of the designer in PDP. In the authors' view, the project method does not devaluate the intuition, the talent or the experience of the designer, but, to the contrary, it aims, starting from a method, to awaken the individual abilities by means of directives and to increase his disposition with regard to creativity. The solution of problems on the most diverse levels of application is a characteristic of this activity and, the authors affirm, the theory of cognitive psychology that studies the essence of human thought must be taken into consideration in the project theory.

5. CASE BASE REASONING FOR CROSS PRODUCT DEVELOPMENT LEARNING

Artificial Intelligence (AI) has shown to be an important tool on the road to task automation. AI is the branch of Computer Science that researches the creation of intelligent systems and has two approaches: a scientific one, geared to the study of cognitive psychology, to understand the processes involved in intelligence; and a technological one, that deals with the representation of these processes by the machine. The tools of AI have been applied in the most diverse domains, from the construction of directed systems to carry out only a single repetitive task to complex attempts to simulate human intelligence (Russel and Norvig, 2004).

The attempts in the direction to use the technology to acquire and to manipulate knowledge have been occurring for decades. In AI, efforts have been made towards the management of delimited areas of knowledge, such as in the configurations of computers and in the diagnosis of illnesses (Davenport and Prusak, 1998).

The area of AI called Case Based Reasoning (CBR) attempts to combine the power of the narrative with the codification of the knowledge. It is a technology to extract knowledge by means of a series of narratives - defined as "cases" - about the subject problem. In contrast to the specialized systems, with structured rules that are well defined, the structures of cases can reflect the fluid thought of a human specialist. In the terminology of CBR, a case usually denotes a problem-situation (Aamodt and Plaza, 1994).

CBR has its origin in cognitive science, whose method is applied for the resolution of problems from the extracted knowledge of previous experiences to solve a current problem. CBR utilizes an ample library of cases for the resolution of problems.

It is about an approach for the solution of problems and for learning based on past experience. One of the advantages of experience is that it provides a historical perspective from which one looks at and understands new situations and events (Davenport and Prusak, 1998).

Wangenheim and Wangenheim (2003) define CBR as "the solution of new problems by means of the use of previously known cases". This tool starts from the basic idea of solving a new problem by remembering a previous similar situation and reutilizing this prior solution to solve the new problem (Fig. 7). The solution can be applied totally or partially, or still, be modified in accordance to the requirements of the new problem.

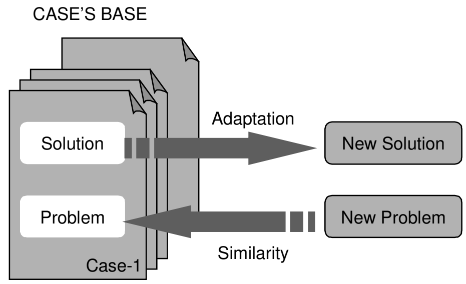

Figure 7. Basic model of CBR approach (Wangenheim and Wangenheim, 2003)

This tool has the characteristic of being similar to the strategy to solve problems adopted by human specialists. The people remember the solution that they themselves elaborated or learned from a determined similar situation like the one they are now facing and try to apply the solutions that they already know without passing through the complex and lengthy process of elaborating a new solution from zero.

Wangenheim and Wangenheim (2003) define the four basic elements of a CBR system:

a) the representation of the knowledge: the knowledge is represented mainly in the form of cases that describe concrete experiences. However, abstract and generalized cases can also be stored in a CBR system;
b) measure of similarity: to be able to find a relevant case for the current problem in the base of cases and to answer the question when a remembered case will be similar to a new problem;
c) adaptation: past situations represented as cases will hardly ever be identical to the ones of the current problem. Advanced systems of CBR have mechanisms and knowledge to adapt the recuperated cases completely, to verify if they satisfy the characteristics of the present situation; and
d) learning: so that the system remains up to date and evolves continuously, whenever it solves a problem successfully, it will have to be capable of remembering this situation in the future as a new case.

The cases are organized and stored in a case base (CB), a set of cases appropriately organized, in a form that can be reutilized (Fig. 8).

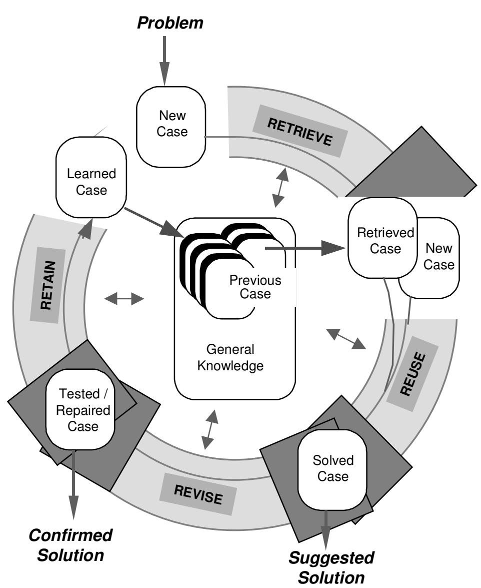

Figure 8. CBR cycle (Aamodt and Plaza,1994)

The CB can contain positive and negative experiences. The positive experiences can contain a description of the solution strategies that successfully contributed to solving a problem. The negative experiences can be a description of frustrated attempts in solving a problem, with the objective to indicate the potential problems, in order to prevent the repetition of previous mistakes (Kolodner apud Wangenheim and Wangenheim, 2003).

The knowledge repository can be structured next to a CB. Richter (apud Wangenheim and Wangenheim, 2003) mentions four structures that a CBR system can store: vocabulary; cases' base; measurements of similarity; and solution adaptation.

Additionally, it is mentioned the capacity of CBR to function as a cognitive model to understand the aspects of thought and of human behavior as one of the advantages of this tool. About this aspect, Janet Kolodner (apud Davenport and Prusak, 1998) affirms that it is a plausible model of cognitive reasoning as well as a method to construct intelligent systems, since it is based on premises and observations of human cognitive common sense and can be applied to a variety of reasoning tasks to obtain greater efficiency and better performance.

In this way, as the CBR presents a series of positive characteristics, linked to learning, it is indicated to assist in the work of the specialists in the resolution of project problems.

6. CONCLUSIONS

This article confirms the necessity of a study of the learning process that is systematized and integrated to PDP. The current studies of learning concentrate on the organizational management level, lacking references about learning at the operational level in a general way and, in particular, in PDP that show the transformation of learning from individual to collective. The difficulties related to learning are due to the complexity of the cognitive process necessary to execute the tasks as well as the complexity of the environment. Therefore, the results presented prove the necessity of support tools to learning directed towards project specialists to assist in the individual learning and the transference of knowledge, and point to CBR as a methodology that can be adequate for this purpose. CBR, also, can contribute to reduce aspects linked to the complexity of the environment, seeing that the knowledge about previous cases allow to better understand the environment of the project and its evolution from the past to the present. By the complex nature of PDP, the lack of learning among different projects demands an orientated approach to the cognitive tasks of the designers, mainly during the initial phases of the project process.

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8. RESPONSIBILITY NOTICE

The authors, Futami, Dalla Valentina and Possamai, are the only responsible for the printed material included in this paper.