Design for Learning and Teaching: A Knowledge-Based Approach to Design Products

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Abstract. In this paper, we will present some prospective ideas which should allow firms' strategic positioning of the market by using knowledge as a key strategic leverage. After presenting the three basic theories underlined design for learning and teaching, paper continues by describing the basic model based upon which we will develop our unique model; knowledge ingenition process. A generic framework is proposed containing a macro-model and a set of micro-models mapping knowledge elements and their dependencies. These models together are necessary to analyze the knowledge situation of the firm and to conceive a roadmap for future trainings of various employees of the firm during the lifecycle of a product. These concepts are illustrated through a part of a case study.

Keywords: knowledge management, design theory, learning theory, ingenition process

1 Introduction

The use of knowledge as an element of differentiation strategy is a quite complex challenge. "Knowledge" of a firm has several forms and contains elements from the firm's trade, structure, culture, and environment. The differentiation strategy offers obviously broad field for business competition and knowledge provides a fertile environment of differentiation. Knowledge must be understood as a vital source of competitive advantage. Following Nonaka *et al.* [1], we think that knowledge is continuously created in a dynamic system resulting from interactions amongst individuals and organizations in a specific context.

According to the OECD [2], the worldwide expenditure in educational systems in the next decade represents something about 2000b$. But products are often designed and industrialized without using a scientific approach toward learning and teaching dimensions. The whole knowledge, generated, stored and re-used in any firm, comes from its activities aiming at answering better and better final customers' needs. These needs should be collected, understood (more or less precisely) and translated into usable constraints for design and development team. In a "classical" product development project (*i.e.* usage-oriented products), these aspects are quite well understood. We call these projects *design for use*, because the main purpose of the product is to be used by customers. Laptops, cars and cell phones are all usage-oriented products. Nevertheless, the research field does not pay much attention to learning/teaching-oriented products (the Sony™ Aibo robot or Lego for instance). As far as we know, there are neither methods nor tools in order to support deeply processes needed to understand direct and indirect customers needs for these products. Moreover, the way that these needs should be used by the firm as a design and development framework is not studied. In other words, the design-for-teaching/learning paradigm is not still developed. Our research addresses precisely this subject.

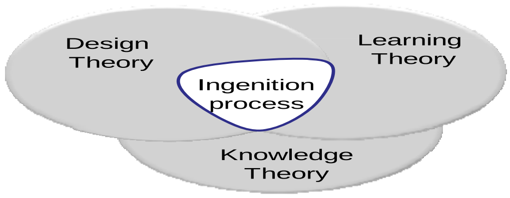


Fig. 1 Underline theories

Before giving more details, it is necessary to notice that two categories of customers are distinguished in learning and training contexts. *Direct* customers (an instructor for example) are those customers who use a product, so a learning/teaching-oriented product, to teach something. *Indirect* customers form the audience (students for instance). Therefore, the design of the learning/teaching –oriented products should take account of the needs of direct and indirect customers simultaneously. Our work stands at the intersection of three basic theories: knowledge theories, design theories and learning theories (see fig. 1). Based on these theories, we will propose an integrated framework to analyze the knowledge generation process under an ingenition model.

In this paper, we propose a new model, so-called *ingenition process. It* considers and then conceives Knowledge generation process based on the ultimate goal of any learning and teaching-oriented product. The rest of this paper is organized as follows. Section two gives a brief overview of the related works in design theories. In the third part we will develop a value chain for knowledge creation process based on semantic transformation. The paper continues by reviewing some literature in learning theories and positioning our work at the heart of these theories. The main concepts of our approach, incorporated in the ingenition process, are presented in section five. We illustrate micro-models through an example taken from the mechanical education. Some conclusions and perspectives will end the paper.

2 Design theories in relation to knowledge

Almost always customers' requirements are defined in terms of usage of the target product. This is the very first set of needs of customers. That is the reason why design theories are mainly focused on usage-oriented services or products. Somehow, design is a process that covers various necessary steps going from the identification of market needs till the realization of the product.

Tollenaere [3] shows that it is necessary to model data and knowledge related to the product from the beginning of the design process. Grabowsky's approach [4] positions the problem into the product lifecycle. Four modeling layers are then necessary: requirements modeling layer, functional layer, physical principles modeling layer and forms modeling layer. Umeda's «Function - Behavior - State» model [5] and the Shimomura's «Function - Evolution - Process» model [6] have similar characteristics by defining the designers' job according to three sequential steps. Andreasen's proposition [7] is focused on knowledge structuring of any product according to four fields, corresponding to the four sequential activities of design: physical phenomena, functions, organs and parts/items.

At the heart of these models, the Design Structure Matrix, (DSM), associated with a product description module is cornerstone of our work. DSM structures the product development phase by splitting it into several problems to solve. This matrix allows keeping track of past paths of design. Fagerstrom [8] uses it and structures the links between designers and sub-contractors in a design process. Lockledge [9] designs an Information System to facilitate communication between actors. Clarkson [10] explain the Visualization techniques to assist design process planning.

Our proposition is not against these theories of design but we consider them as approaches to be included in the practical aspect of our framework. That means we have been influenced by some various parts of several models. Closer to our research field, Norman [11], Maier and Fadel [12], Brangier [13] and later Brown and Blessing [14] works on the concept of "affordance". It refers to the capacity of a product to be understood and used without additional information. This concept is clearly related to classical products to be used by customers. However, it is possible to use this concept as well to qualify a learning/teaching product because even in this context products should be easily used by direct and indirect customers. To complete the qualification of a product, we propose the concept of "learnability" which refers to the capability of a product to support the process of knowledge transmission connecting direct customers to indirect customers. This concept includes the affordance. The "learnability" of a given product can be assessed, analyzed and improved by applying the ingenition process as it will be described hereafter.

3 Knowledge theory: a model proposition

Holsapple and Jones [15] developed a value chain for KM process and activity. Lee and Yang [16] explained a knowledge value chain for all activities concerning KM. These endeavors are mainly theoretical and focus on activities in organization and a macro view of whole knowledge based view. We suppose that the problem of semantic view of KM, basically what happens and changes in the nature, content and context of concepts when transforming data to wisdom is unsolved.

In the value chain of knowledge creation, our goals are at first to valuate knowledge and the process that lead to organizational wisdom and in second to propose a conceptual framework that brings together basic semantic concepts in a universal way.

Knowledge value chain consists of the basic elements of semantic transformation, value processing activities, and output as final margin that here is knowledge performance. These processing components and activities are the building blocks by which a corporation creates a product or provides service valuable to its customers. Several authors tried to make a distinction between data, information, and wisdom; some of them add a category as understanding [17]. In this paper we will try to make a distinction between data, information, knowledge, individual wisdom as competence or expertise, and collective wisdom as capability. This framework is drawn upon consciously and deliberate management of these activities as a global umbrella to bring together all transformation activities that lead to value creation for organizations. Fig. 2 depicts components of VCKC.

Based on the assumptions that each step and situation of this value chain is considered as in a unique time, unique place and context and with unique person, one of the results in this work is to open a window for information and engineering researchers to consider epistemological concepts in KM based upon process view.

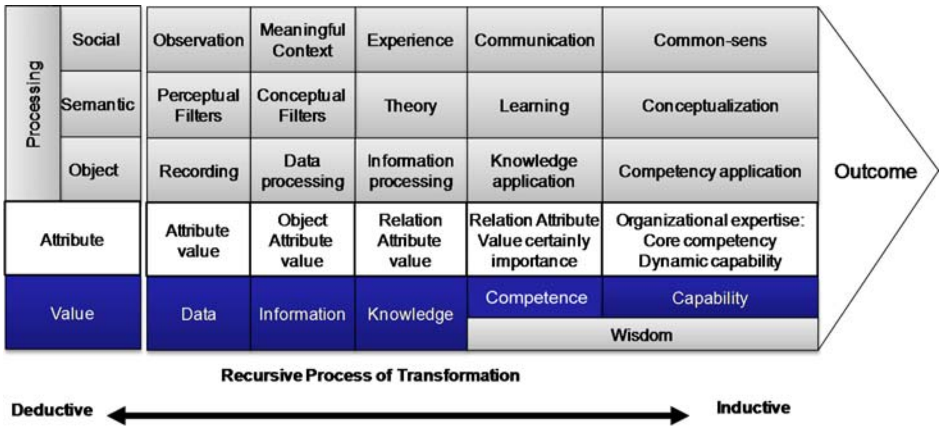


Fig. 2 **Value Chain of Knowledge Creation (VCKC)**

4 Learning theory

In this field, we explore and compare our proposition with Giordan's proposition [18]. We will try to show that our model will be able to integrate all characteristics of this model. Research on knowledge and learning is currently converging towards several key findings. This specifically highlights the limits of both traditional teaching practices and of several innovations (active, non-directive, discovery methods).

The appropriation of knowledge results from design transformation processes in which the designer-learner must take the leading role. Knowledge acquisition is the result of elaboration activity during which designer-learner compares new information with mobilized knowledge and produce new meanings, which in turn are more appropriate for answering their questions. The main theories on learning are all quite limited in this respect. Therefore, to understand learning processes we must develop a new model that could integrate the parameters which challenge the mobilized designs. One attempt was initiated at the LDES in 1987 [19] and since 1989 it has been refined [20]. The model is now known as the Allosteric Learning Model (ALM). This model defines the issues, explain the main characteristics of learning, and allow predictions.

All of the theories require a detailed analysis in order to determine their overall potentials and limitations with regard to educational and cultural practices. Apart from certain cognitive approaches, learning is not the original focus of any of these theories but is considered, at best, as a potential side effect. However, when studying learning, we cannot just focus on learners and their conceptual mechanisms. Although they own self-organization capabilities, they are largely inter-dependant and related to conditions and to the successive environments through which they have emerged during each individual's history. To fill this gap we have tried to develop a new model, which combines 'interaction' and 'elaboration' but also 'integration' and 'interference'(fig. 4). In ALM, as explained above, learning is not dependant on a single factor, but on a network of conditions we call the 'didactic environment'; this is overwhelmingly important for teaching and for science popularization in general.

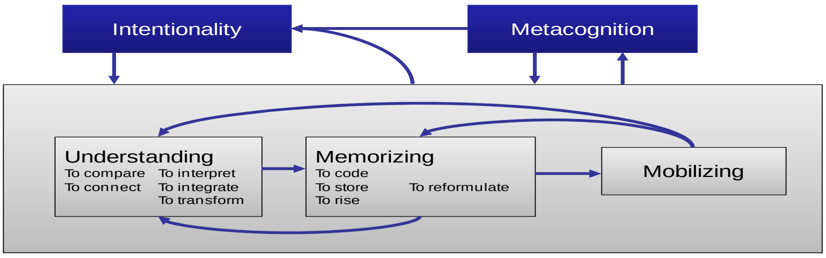


Fig. 4 Allosteric Learning Model (Giordan, 1994)

5 Ingenition: a process to improve design for learning/teaching

The whole ingenition process is based on a cycle which studies two joint knowledge and competence fields (fig. 5). During the very first step of this process, a *macro-model* is defined (the grid on the top of the scheme) in order to determine the strategic orientations of the firm in terms of internal trainings for employees and external learning/teaching acquisition for customers. Then teaching/learning situations supported by learning/teaching-oriented product are studied in order to understand real customers' needs. These situations are modeled by AS IS "graph of knowledge elements" called also the ingenition micro-models. These graphs are obtained after observations of actions and reactions of trainees and their teacher during the teaching/learning processes.

After analyzing the graph, regarding various available references and target competences, several TO BE knowledge graphs may be established. Once assessed and analyzed, the most relevant graph is chosen and it will be used as a main framework from which specific constraints for design should be extracted. Moreover, from this new graph, protocols regarding training sessions could be identified in order to optimize customers' satisfaction by offering more efficient learning sequences to direct customers.

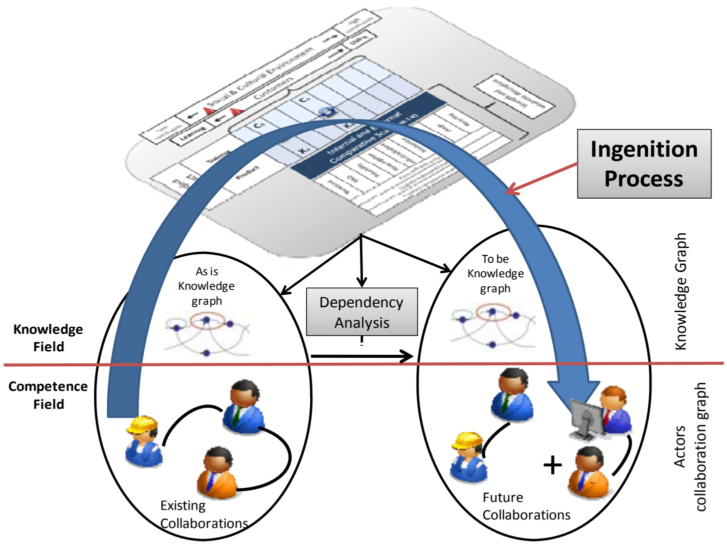


Fig. 5 General Ingenition framework

5.1 Ingenition process Macro model

When a project leader conducts its mission, (s)he should have a cross-functional (horizontal) view of it. By extending this notion to the whole product lifecycle, it can be seen that the learning process could cross the lifecycle phases. It means that there is a learning process parallel to the whole lifecycle. This is obviously not the case of the system managers who have very often a functional (or vertical) view of a given part of the system. This means that for a given product development project, it could be necessary to model all necessary learning activities within a global model covering both vertical and horizontal learning processes. We use a macro-model to represent these two complementary views of the same learning process (Fig. 6). Once established, this model makes possible the identification of most critical elements and of the life cycle of product development and to act consequently.

5.1.1 Environmental descriptors

5.1.1.1 Product characteristics. A product is used either for usage or learning and its characteristics (functional, structural and behavior) would not be the same. Obviously, there is a continuous scale going from the purely usage products to purely learning ones. The social and cultural constraints have to be also taken into account. By schematizing these constraints with a relative position of a cursor on a continuous scale, the socio cultural context of the product's environment is defined. Audits of experts of the firm will allow the definition of the relative position of these cursors.

5.1.1.2 Extended product analysis. A learning/teaching oriented product is an extended product containing at the same time not only the physical product but also some associated services. We consider training as one service associated to the physical product. By integrating knowledge elements accumulated in the firm (represented by K∆), it is supposed that it will be possible to generate new competences (represented by C∆) for indirect customers. The difference between knowledge and competence and the process which allows transforming knowledge to competence is based on Giordan's allosteric model [18].

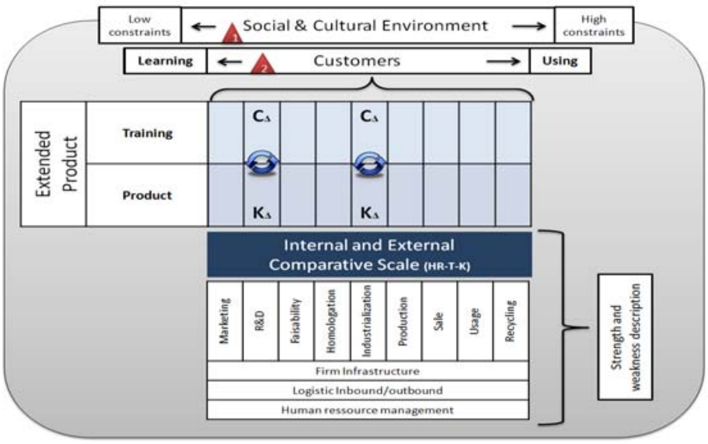


Fig. 6 Ingenition process macro-model

5.2 Ingenition process micro-models

The main purpose of the ingenition process is to focus on competences and the way to obtain C_Δ from knowledge K_Δ . Competences are those knowledge elements gathered, structured and usable by users and obtained during various trainings sequences. Formally we may model this main interaction by $K_\Delta \xrightarrow{i} |C_\Delta$. The vertical line stands for training sequences. The transformation of knowledge to competences uses specific supports. One or several Learning Object (LO) may support this process, modeled by $K_\Delta \xrightarrow{i,\{LO\}} |C_\Delta$. For example, both the software package implemented in a robot and the robot itself represent the two learning objects for a specific learning purpose; see for instance [21].

From a generic point of view, it is possible to decompose K_Δ into a sequence of dependent and more detailed knowledge elements. The scheme at the left side of Fig.

7 represents this graph. Ci and Cf correspond respectively to initial and final level of competence of indirect customers. Then C_{Δ} corresponds to the difference between these two levels of competence. Within the ellipse, we can see the graph of dependent knowledge elements. The ellipse models the frontier of the studied ingenition process. Each couple of knowledge elements is connected together by a dependency link. (K1, is required for understanding of transistor, K2). This graph, which allows providing a competence to some trainees, is supported by a set of learning objects. The whole process is performed by actors but for simplicity they are omitted in the scheme.

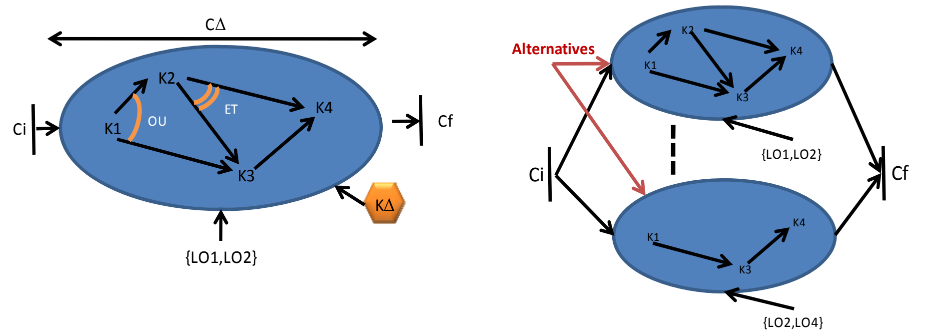


Fig. 7 Knowledge dependency graph

The analysis of the knowledge graph can be based on various dependencies identified within the graph. Three basic logical dependency relationships may be identified within the graph: **Antecedence**: The understanding and description of Kj is not possible without explaining Ki. **Parallelism**: The understanding of Ki and Kj is independent. **Simultaneity**: K1 and K2 should be treated at the same time.

Consideration of these various dependencies could define directly the way that various learning objects are used: *As Is situation*. By analyzing these scenarios regarding target competencies of a learning situation, learning objects and their connections, and strategic learning decisions made within the ingenition macro-model, it should be possible to build learning alternatives (the schema at the right side of Fig. 5): *To Be situation*.

Each learning alternative defines target competences, necessary learning objects, and the graph of knowledge dependencies. The definition of these alternatives imposes structural and functional constraints on the learning objects design and realization.

The knowledge dependency graph obtained based on the analysis of target competence (Cf) is called *primary dependency graph*. Based on the choice of learning objects, complementary graphs may be added to the primary graph in order to let the indirect customers reach the target competence. These complementary graphs are called *auxiliary graphs* and their existence and complexity may give a clear indication of the learning/teaching efficiency. Using an engine to show fixed pivot liaison could require complementary knowledge to include in the learning/teaching sequence; auxiliary graph. In section 6, these two types of graphs will be illustrated more in detail.

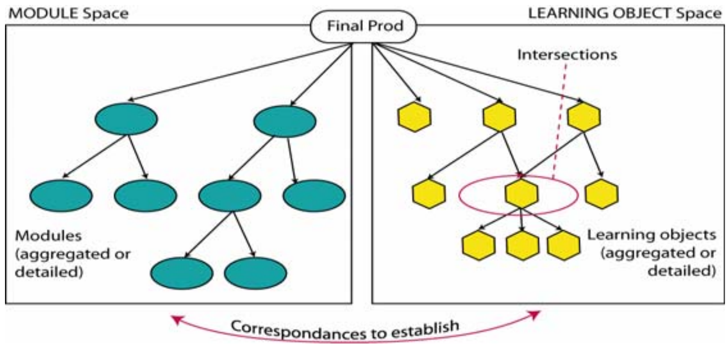


Fig. 8 Modular and Learning spaces

5.3 Learning objects, learning products and design process

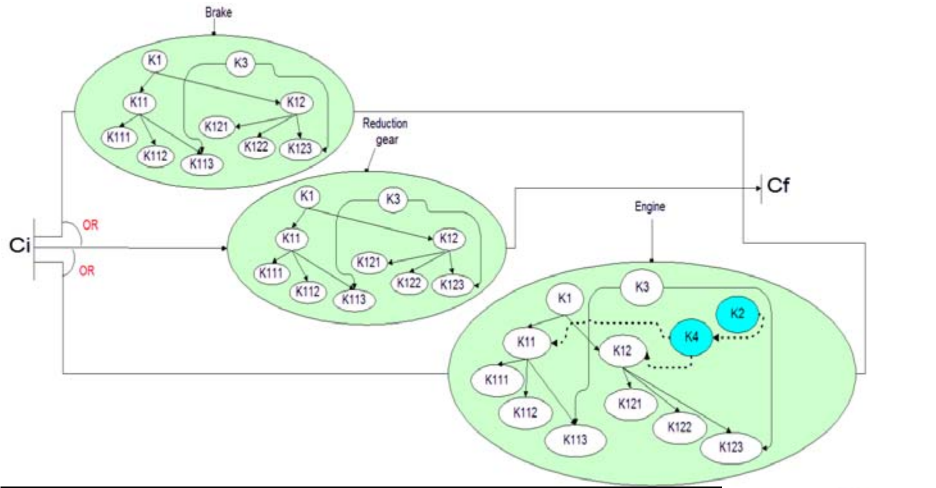
A product may be seen from various points of view: design, realization and learning for example. All of these definitions should be connected to the design point of view. In fact, this view determines the rest of the product development and usage process. From the learning point of view, a product is decomposed into an arborescence of learning objects (defined in the past section). Every node of this decomposition corresponds to a real learning object. A learning object is a collection of product modules which can be used as a support for knowledge transmission. Defined as such, it is clear that there could be intersections between two learning objects taken separately while there is no intersection between two modules. But, modules have mutual exchanges. These are the main differences between learning objects and product modules. Fig. 8 represents these two decompositions of a given product.

6 Description of case study

This model is applied to a French company called here *Innovia*. Innovia designs and produces products for primary, high schools and universities. Innovia's top management looks for a new product to support training mechanical devices in high school. The product is a small airplane. Its cultural and social environments do not impose hard constraints on the product (see cursor 1 on the top of the fig. 6) that is the reason why the cursor is positioned at the left end of the scale. Another cursor (triangle cursor 2 on Fig. 6) is positioned on the usage scale. This scale addresses the first usage of the product goes on a continuum from purely learning oriented to purely usage oriented. For this airplane, Innovia selects a highly learning oriented level. Direct implications of these two scales in terms of shape, materials, maneuverability, etc. of the product should be taken into account from the beginning of the New Product Development project.

The micro-models were developed to represent potential alternatives for teaching fixed pivot (K11) and sliding pivot (K12) connections. Each type of connection can be taught by at least one the following approaches: cinematic 2D diagram (K111 or

K121), cinematic 3D diagram (K112 or K122) or by their torsor expressions (K113 or K123). Before teaching pivot liaisons, it is decided to teach also the solid mobility in space (K1). By representing all these knowledge elements, the primary dependency graph is obtained and is shown in the ellipses (Wight nodes and plain edges). Three potential learning objects may be used to illustrate the pivot liaison: a bicycle brake, a reduction gear or an engine (ellipses of fig. 9). Primary graph is the same for these three solutions. However, by using the engine, it is clear that additional knowledge elements should be included within the knowledge dependency graph. This is the auxiliary graph which contains: the main power transmission theory (K4) which requires a good understanding of fundamental mechanical concepts such as energy, force, power and work. The auxiliary graph is represented by the blues nodes and dotted edges.



K1	Solid mobility in space	K12	Sliding Pivot
K11	Fixed Pivot	K121	Cinematic 2D sliding Pivot
K111	Cinematic 2D fixed Pivot	K122	Cinematic 3D sliding Pivot
K112	Cinematic 3D fixed Pivot	K123	Torsor of a sliding pivot
K113	Torsor of a fixed pivot	K3	Torsor manipulation
K2	Power, Energy, Work, Force	K4	Power transmission

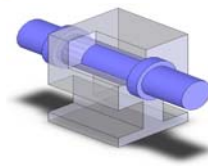


Fig. 9 Micro-model of the pivot linkage

Some observations were made according to these micro-models: 1) Primary graph. It is necessary to identify clearly the primary knowledge dependency graph. A deep analysis of this graph helps to extract recommendations for designers and also for direct customers. 2) Auxiliary graph. In this example, it can be seen that including complex learning-object such as an engine in the learning-oriented product could diminish the learnability due to the increasing complexity of the graph, i.e. by including various supplementary elements. This is an important indicator of efficiency for final users. 3) By extracting primary and auxiliary graphs, new learning objects may be necessary to make them understandable. 4) It may be possible to analyze various alternatives in a performance assessment strategy in order to choose the most relevant learning object to the expected target and also to the trainees' specificities.

7 Conclusion

In this paper, we study the learning dimension of a product. It is argued that knowledge generation not only represents an important internal innovation source but also, the firm can use the learning and generated knowledge as a tool for positioning firm on the market. In this paper we present the basic underline theories with which we developed our unique framework in knowledge ingenition process. Based upon the model proposed as VCKC, the explanation of some related design theories and the positioning of the learning theories context, we introduced an ingenition process as a global framework.

We propose the two models of the ingenition methodology. This methodology is built to ensure two goals: analysis and design of learning/teaching-oriented product and analysis and design of learning/teaching sequences. The ingenition is a methodology to engineer learning/teaching processes. An illustrative example is presented at the end.

In short, the main tool presented here, the learning grid allows: 1) To model the social and cultural environment regarding learning purpose of the firm. 2) To underline the purpose of the product, learning or using or something in between. 3) To keep track of Knowledge generated in relation with the activity considered. 4) To measure the variations between what the firms can do inside and what it should be outsource.

The micro-models represent the knowledge dependency graphs. These graphs should correspond at least to the map of necessary knowledge for a given purpose. Each graph is supported by one or several learning objects.

Our research is focused on a highly dynamic market: Education market. We are aware of the fact that a huge amount of works still has to be done in this field. Authors are working on a complete description of the ingenition methodology and would apply it in 20 schools of south-west of France. The results of this study will consolidate the ingenition approach.

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