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Design for teaching and learning

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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. These ideas are focused on new knowledge creation and preservation, for customers as well as firm's employees. To do so, 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 small part of a study case.

Keywords: Ingenuity process, knowledge, learning, design

1. Introduction

According to Porter [1], the rules of business competition are embodied in five competitive forces: Entry of new competitors, Threat of substitutes, Bargaining power of buyers, Bargaining power of suppliers, and Rivalry among the existing competitors. These rules may be amended by a subtle and complex competitive force related to "knowledge creation and management" during all phases of the product lifecycle. 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.* [2], we think that knowledge is continuously created in a dynamic system resulting from interactions amongst individuals and organisations in a specific context. But not all of these knowledge elements are explicit.

The very important specificity of the research done here is that the studied products are *learning/teaching-oriented*. This self-explanatory concept focuses on the way that a product participates and supports any knowledge transmission. Before giving more details, let us notice that two categories of customers are distinguished in the 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.

The whole knowledge, generated, stored and re-used in any firm, comes from its activities for 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 and studied hardly. We call these projects *design for use*, because the main purpose of the product is to be used by customers. Laptops, cars, cell phones ... are all usage-oriented products. Nevertheless looking at learning/teaching-oriented products (the Sony™ Aibo robot or Lego for instance), ironically, the research

field is quite poor. As far as we know, there are no methods and tools to study 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 paradigm of design-for-teaching/learning is still empirical. Our research addresses precisely these subjects.

In this paper, we propose a new model, called *ingenition process* which engineers Knowledge generation process based on the ultimate goal of any learning and teaching-oriented product which has to be to answer customers' needs in terms of competency acquisition. The rest of this paper is organised as follows. Section two gives a brief overview of the related works. Main concepts of our approach, ingenition process, are presented in section three. We illustrate micro-models through an example taken from the mechanical education. Some conclusions and perspectives will end the paper.

2. A brief state-of-the-art

Almost always customers' requirements are defined in terms of *usage* of the target product. This is the very first set of needs of clients. That is the reason why, the design theories are mainly focused on usage-oriented services or product. Design articulated around the description of the forms, the structures, of the functions, is a very well studied field. Somehow, design is a process that covers various necessary steps going from the identification of market needs till the realization of the product. This process is sequenced by various intermediate states of representation of the product, such as the requirements, the sketches, the models or the prototypes. Tollenaere [3] shows that it is necessary to model data and knowledge related to the product from the beginning of the design process. Several methodologies study the product knowledge representation possibilities by solving specific problems such as design phase or other phases of the product lifecycle. De Martino in [4] treats the multi-facet models (geometric and simulation). Holmqvist studies the product architecture for products with great varieties [5]. Finally, the integration between the geometrical definition of the product and the physical behaviour is treated in Concurrent design, applied artificial intelligence by Finger [6]. In this school of thought, the "Function - Behaviour - State » model in Umeda [7] and the « Function - Evolution - Process » model in Shimomura in [8] have similar characteristics by defining the designers' job according to three sequential steps. Andreasen's proposition in [9] is focused on knowledge structuring of any product according to 4 fields, corresponding to the four sequential activities of design: physical phenomena, functions, organs and parts/items. The multi-model of product, developed by Tichkiewitch in [10] envisages the innovative design which looks for stocking product knowledge coming out from various core businesses and jobs and managing their interactions during the product lifecycle. The multi-model approach conducts to functional and structural graphs. One or several physical components are associated with a function and vice versa. This leads to the identification of parts, their functions and interactions within the product.

The prototype allows the use of those professions and jobs which participate to the definition of the primary phase of the approach. In short, the designed prototype (and the product) has a unique architecture with several facets related to professions (assembly or turning for instance). This structure permits to keep track of past objectives and actions according Ouazzani in [11] which push designers towards specific solutions. But, in this work, the operational aspect is not studied and the links between this model and the others activities of a process or with the product itself are not mentioned. This, from our point of view limits largely the study of possibilities of knowledge generation, reuse and capitalisation.

Closer to our research field, Norman in [12], Maier and Fadel in [13], Brangier in [14] and later Brown and Blessing in [15] 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 those products that will be used by customers. However, it is possible to use this concept to qualify a learning/teaching product because even these 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 products can be assessed, analysed and improved by applying the ingenition process as it will be described hereafter.

3. Ingenition: a process to improve design-for- learning/teaching quality

The whole ingenition process is based on a cycle which studies two joint knowledge and competency fields (see figure.1). 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. The details of this model are given in the next section. Then teaching/learning situations supported by learning/teaching-oriented product are studied in order to understand real customers’ needs. These situations are modelled 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.

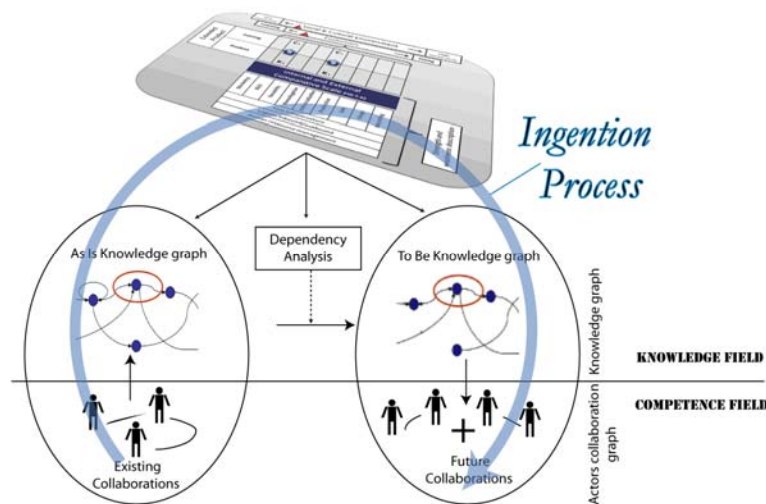


Figure.1: General Ingenition framework

After analysing the graph, regarding various available references and target competencies, several TO BE knowledge graphs may be established. Once assessed and analysed, 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. The complete ingenition methodology is not described here; we describe only its two main tools hereafter.

3.1. *Ingenition process Macro model*

When a leader of project within the meaning of Nonaka [2] 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 (Figure.2). Once established, this model makes possible the identification of most critical elements and of the life cycle of product development and to act consequently.

It is important to note that we endeavoured to allow the integration of all the techniques of creativity, of design which are collaborative, co-operative, distributed, and participative. Typologies of Sriram [16] or Gero [17] can be integrated into this model. Let us define the main components of this macro-model.

1) Environmental descriptors

-Product characteristics.

- A product is used either for usage or learning and its characteristics (functional, structural and behaviour) 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 by 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.

-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. In our case, in order to simplify the study, we consider the physical product and with one service associated to it which is training. It is supposed that by integrating knowledge elements accumulated in the firm (represented by K_{Δ}) it will be possible to generate new competencies (represented by C_{Δ}) for indirect customers. The difference between knowledge and competency and the process which allows transforming knowledge to competency is based on Giordan [18] and his allosteric model.

2) Model of the added-value

The low part of the grid uses the model of added-value developed by M. Porter. The major asset of this modelling resides in the fact that the main functions and supports of the development process of new product are present simultaneously.

3) Learning strategic SWOT analysis

This area of the grid summarizes the result of a strategic analysis of training on the level of each primary function. The analysis allows a comparative analysis of the situation in various sectors of the firm. We collect all information concerning the human resources (competences), tools (tools, process and infrastructures) and knowledge available within the differences services. The aim is to quickly identify what the firm will be able to make in-house and what it will be obliged under discussing.

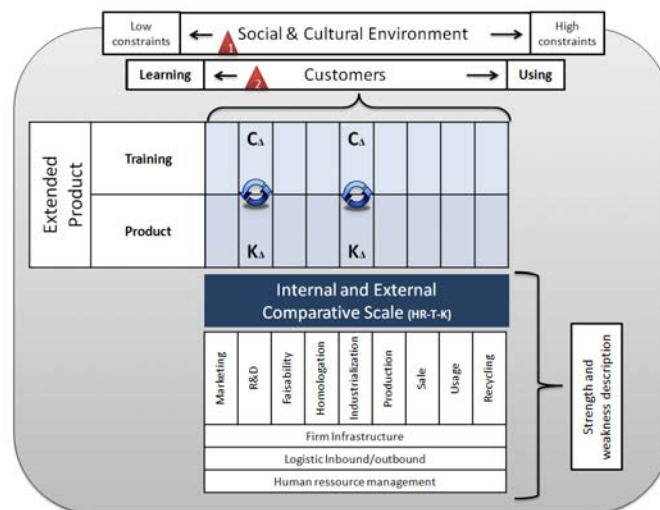


Figure.2: Ingenition process macro-model

3.2. *Ingenition process micro-models*

The main purpose of the ingenition process is to focus on competencies and the way that C_{Δ} are obtained from knowledge K_{Δ} . Competencies 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 ingenition process looks at this transformation process. The transformation of knowledge to competencies uses specific supports. One or several Learning Object (LO) may support this process, modelled 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 [19].

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 the Figure.3 represents this graph. C_i and C_f correspond respectively to initial and final level of competency of indirect customers. C_{Δ} corresponds therefore to the difference between these two levels of competency. 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. For instance, K_1 is a necessary knowledge element for K_2 (electricity basis, K_1 , is required for understanding of transistor, K_2). This graph, which allows providing a competency to some trainees, is supported by a set of learning objects. The whole process is performed by actors but for simplicity they are omitted from the scheme.

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 K_j is not possible without explaining K_i . In this case, K_i is an antecedent of K_j (matrix representation before explaining torsors).
- **Parallelism:** The understanding of K_i and K_j is independent. K_i and K_j may be explained without considering each other (Ohm law and Newton's laws).
- **Simultaneity:** K_1 and K_2 should be treated at the same time. All properties (several knowledge elements: transitivity, commutativity ...) of the Boole algebra should be taught simultaneously when presenting this theory to students.

Consideration of these various dependencies could define directly the way that various learning objects are used (As Is situation). By analysing 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 Figure.1); To Be situation.

Each learning alternative defines: target competencies, 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 realisation.

The knowledge dependency graph obtained based on the analysis of target competency, C_f , is called the *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 competency. 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 4, these two types of graphs will be illustrated more in detail.

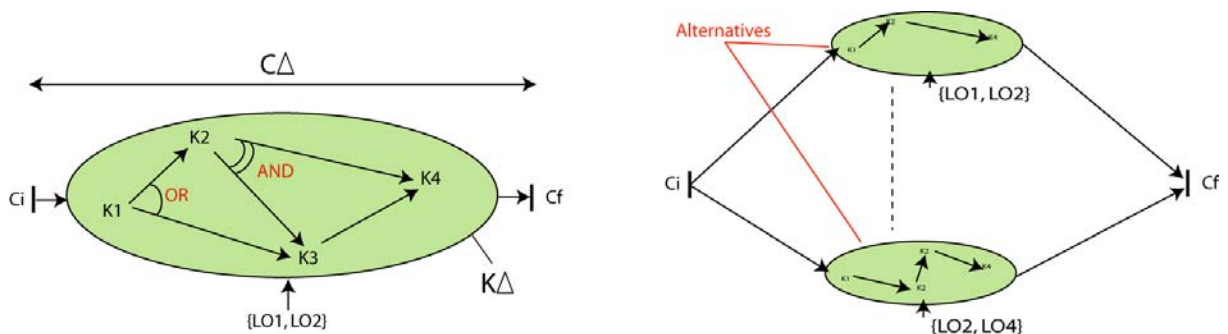


Figure.3: Knowledge dependency graph

3.3. Learning objects, learning products and design process

A product may be seen from various points of view: design, realisation ... and learning. 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. Figure.4 represents these two decompositions of a given product.

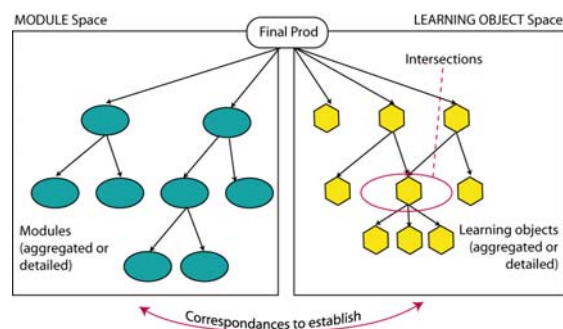


Figure.4: Modular and Learning spaces

4. Description of case study

This model is applied to a French company called here *Innovia*. Innovia designs and produces products for primary and high schools and even university. Innovia's top management looks for a new product to support training in high school for mechanical devices. The product is a small aeroplane. Its cultural and social environments do not impose hard constraints on the product (see cursor 1 on the top of the Figure.2). That is the reason why the cursor is positioned at the left end of the scale. Another cursor (triangle cursor 2 on Figure.2) 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 Using oriented. For this aeroplane, Innovia selects a highly learning oriented level. Direct implications of these two scales are in terms of shape, materials, manoeuvrability, etc. of the product and 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) liaisons. Each type of liaison 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 the figure.5). 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.

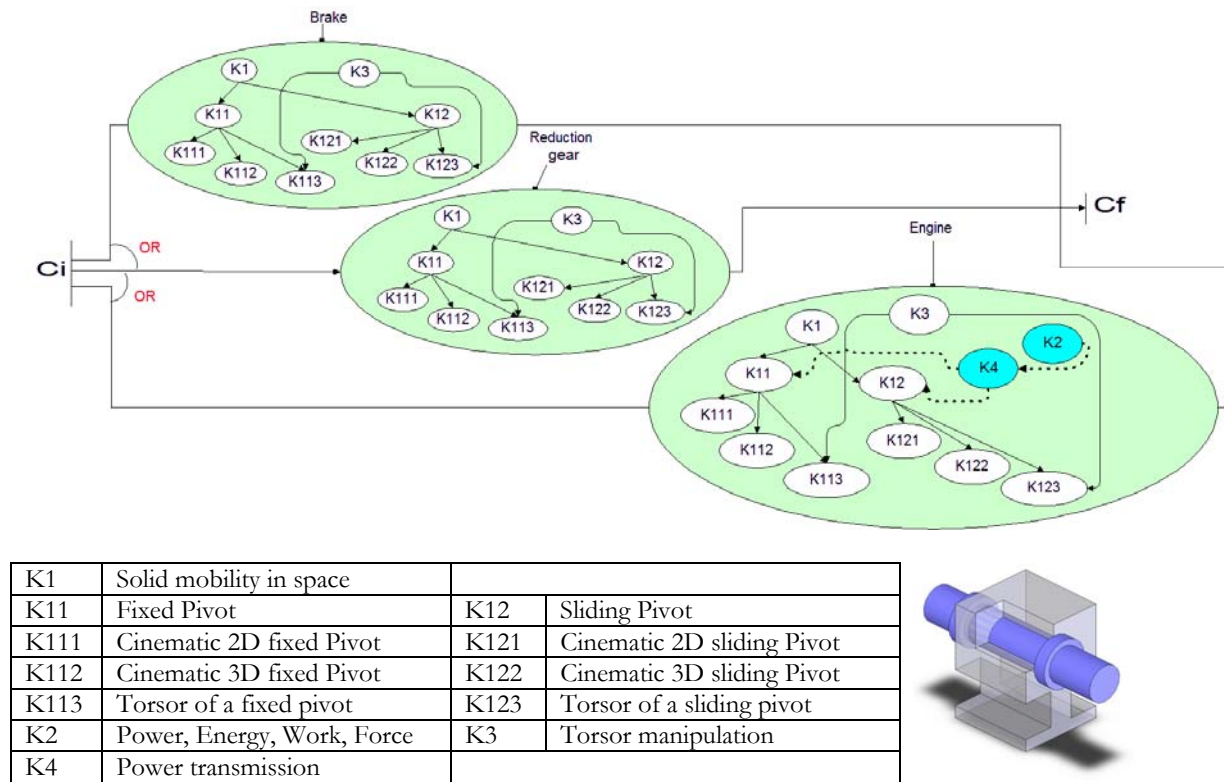


Figure.5: Micro-model of the pivot linkage

Some observations were made according to these micro-models:

- 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. By doing so, we are engineering learning/teaching sequences.

- Auxiliary graph. In the case of 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. Almost every learning/teaching sequence could contain a more or less complex auxiliary graph. This is an important indicator of efficiency for final users.

- By extracting primary and auxiliary graphs, new learning objects may be necessary to make them understandable.

- It may be possible to analyse various alternatives in a performance assessment strategy in order to choose the most relevant learning object to the waited target and also to the trainees' specificities. It means that the reduction gear system could represent a better solution than a bicycle brake in some learning situations.

5. Conclusion

In this paper, we study the learning dimension of a product. It is argued that knowledge generation does not represent only 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. After a state-of-the-art, we propose the two models of the ingeneration 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 ingeneration 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:

- to model the social and cultural environment regarding learning purpose of the firm.
- to underline the purpose of the product, learning or using or something in between.
- to keep track of Knowledge generated in relation with the activity considered.
- to measure the variations between what the firm can do inside and what it should be outsource.

The micro-models represent knowledge dependency graphs. These graphs should correspond at least to the necessary map of 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. According to the OECD [20], the worldwide expenditure in educational systems in the next decade represents something about 2000b\$. But unfortunately often products are designed and industrialized without using a scientific approach. We are aware of the fact that a huge amount of works still has to be done in this field. The approach has been experienced partly in one of the biggest German industries of education sector and allowed them to stop a new product development project! 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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