The collaborative work and product development: a didactic experience in undergraduate courses

Roberta Pereira Nunes
Universidade Federal de Juiz de Fora - UFJF, Campus da UFJF, Departamento de Engenharia de Produção, Juiz de Fora, Brazil
roberta.nunes@ufjf.edu.br

Marcos Martins Borges
Universidade Federal de Juiz de Fora - UFJF, Campus da UFJF, Departamento de Engenharia de Produção, Juiz de Fora, Brazil
marcos.borges@engenharia.ufjf.br

Romir Soares de Souza Filho
Universidade Federal de Juiz de Fora - UFJF, Campus da UFJF, Departamento de Engenharia de Produção, Juiz de Fora, Brazil
romir.soares@gmail.com

Abstract - **This paper reports some experiences in the Product Design II discipline at the Production Engineering undergraduate course in the UFJF, Brazil. The focus of the discipline is to allow the students to experience the team work product design process from the conceptual phase to the prototype construction. During one semester the teams have to develop the initial product idea considering the integration of many disciplines. At the end each group has to build a prototype and document the design solution. They have to consider the several restrictions imposed by the design problem itself, including material selection, manufacturing processes, packing, among others. This assignment also involves the use of web platform environments to help collaborative work with the use of different ways of information treatment and optimization in order to organize the design process and learn from the information. The experience has shown that much of the time and many of the resources allocated in the design development step are lost not because of poor development practices, but due to a lack of better management of information and communication tools. Also this design problem is associated with a series of practical exercises, called *rapid design*, that aims to enhance the product design teaching and learning process in various fields of knowledge such as graphic representation, mechanisms, data and information management. Those exercises also act as an initial approach to the design process and help to break some initial barriers from the student side. The partial results that can be observed from those experiences show that the use of rapid design exercises and a structured team work design process with the use of web-based tools has a great role in the students motivation that can be observed in the final design documentation and prototypes presented at the end of the semester.**

Index Terms – Didactic experiences; Product design; Teaching and learning process; Web based environments.

INTRODUCTION

It is common sense that one of the basic roles of the engineer is to manipulate materials, energy and information with the aim to create benefits to the human kind. Also those benefits can take the form of a discrete product, a service or a process. Other authors consider the design process in the center of intersection of cultural and technological activities. In the case reported here, the methodologies and processes introduced in the discipline are mostly concentrated in the development of discrete industrial products. There are also a huge focus on the rigor and the consistency in the method used, beyond the result of the process itself [8].

According to Slack et al [6] and many other authors, the main objective the product design process is to provide products, services and processes which will meet the early identified consumer needs. The design team must create esthetically pleasant artifacts that must meet or exceed consumer expectations. This process starts out with a concept and ends in the translation of this concept specifying something that can be produced.

According to Naveiro [8], designing a product or a building involves perceiving the artifact structure. This structure continuously changes along with the progress of the project just as designing involves establishing stages and phases, evolution levels, which consolidate a body with new ideas that emerged along the process. The artifact attributes captured by the participants, and its relationship with the whole, allow us to clarify the organization of the project tasks against the current stage of the design, and in harmony with each team member's universe of specialization. In this sense, designing is considered much more of an effective communication and cooperation, a negotiation and decision-making setting, in which team members have a shared knowledge enabling them to perceive what is relevant to be shared and how to usefully introduce information to the team.

However, is frequently observed that in the product design process there are made decisions that don't take in account the manufacturing process of a component or system. This fact is of significant importance since small changes in the product or service design in the early stages of the process can have important consequences in the manufacturing costs of the product [10].

Special attention should be given to the concurrently stages development in order to reduce design time and broaden the integration among the design interfaces. Thus, special attention is given to the manufacturing and assembly process by selecting the production technology, production design and production plan, at the same time as the product's conception, in order to more effectively integrate the product characteristics and specifications to the company's production system [5].

The current approach to the product development process does not allow the consideration of the design process as a mainly intuitive activity. It is now an application of a systematized methodology orientating the work from task assignment till the final detailed design.

Product development is a process integrated with other disciplines and has become one of the key processes for competitiveness reinforcing the multidisciplinary aspect of learning.

In this sense, designing can be considered much more an effective communication and cooperation process, a negotiation and decision-making setting, in which team members have a shared knowledge enabling them to perceive what is relevant to be shared and how to usefully introduce information to the team.

In that way, this paper presents an didactic experience on product development, describing the methodologies used to orientate the process and showing the use of computers as tools to mediate communication among the actors involved, bringing new sources of information, and providing tools for the development and storage of final products information's. In the end the paper presents examples of designs developed by the student's teams.

THE PRODUCT DESIGN DISCIPLINE

The Product Design II discipline follows the Product Design I in the curricular structure of the Production Engineering course at UFJF. In the first discipline the main task is to develop a small electric powered vehicle [2]. For that there are approached some theoretical aspects of product design methodologies linked with an overview of some electronic, mechanical and structural concepts.

In the second discipline the aim lies in the development of a technical product of low to medium complexity, based on market needs and other considerations researched by the students. The product to be developed is a result of a student's choice, oriented by the teacher.

The discipline deals with the concepts of product development process and reference models in an attempt to prepare Production Engineering students to apply tools, methods and techniques in their future professional lives

In this sense, one of the aspects to consider is the interface with other disciplines involved in the conception and execution stages of the product design. There are several disciplines which contribute to the development of the project of an artifact. Factors such as geometric shape, sizing, ergonomics, materials, costs and production process among others, define a set of disciplines considered in the product designing.

There is proposed to the students teams a practical exercise – rapid design exercise – within a systemic product development process that integrates other disciplines, such as, manufacturing processes, marketing, ergonomics, materials engineering, economic viability, among others.

In this context, the development of the rapid design exercise is not directly linked to the technology used or to the complexity of the product but to the activities to be developed during the school semester. However, there is stimulus for the use of information integration mechanisms.

The didactic experience took place during a semester by students enrolled in the Product Design II discipline; in the Production Engineering course at the Federal University of Juiz de Fora.

DESIGN METHODOLOGY

The development of a product can be considered as a system that can be unfolded into normally interdependent overlapping phases. Among other approaches, these phases can be defined as conception, planning, execution and conclusion, responsible for the life cycle of a project. These phases are processes which occur along the project and its achievement surpasses the graphic display or solution of the idea, incorporating a number of considerations and conditionals [4]-[5]-[6].

The concept of Concurrent Engineering consists of simultaneously carrying out the product development stages which were traditionally done sequentially [8]. Thus, product planning, product engineering and process engineering activities must be managed simultaneously in order to optimize information, interfaces and connections among them. In the case reported here, the student's teams must encompassing experts in the several knowledge areas of the product such as teachers of other disciplines who can contribute and bring up some knowledge and information in the early steps of the process.

Design is also seen as something with a great deal of innovation. However, in companies, the current design practice is mostly concentrated in the modifications and in the incremental improvements of the product. Many projects have a high innovative content, but most of the projects follow a different pattern, where innovation is not high.

The classes of design commonly found in industry are adaptative design and variant design, which involve the use of known strategies, or established design plans to arrive to new solutions. In these cases, the problem decomposition strategy and some classes of solution are already known. In other words, the initial perception of the product structure is known and the disciplines needed to solve the design problems are already identified, as, for example, the case of designing townhouses and apartment-buildings. However, there is always some particularity in the design constraints, and different types of knowledge are always required in the design activity.

In this didactic experience there were used an appropriate methodology for the development of a low to medium technical complexity product design. The methodology used as a means to provide orientation is comprised of five stages: Concept Generation, Concept Selection, Preliminary Design, Architecture Design (Design Assessment and Improvement), and Detailed Design (Prototyping and Final Design).

The **Concept Generation** transforms an idea for a product or service into a concept indicating the shape, the purpose, the object and the benefits of the initial idea. The concept can be created through inside sources such as the analysis of consumer need, suggestions from the sales and/or front line personnel, and also from outside sources such as market research, client suggestions and actions taken by competitors .

The **Concept Selection** involves design assessment criteria in which technical and financial viability, acceptability and vulnerability analyses are done as a means to assure it is a sensible addition to the client/company's product and services portfolio. This stage also includes the following steps: validating the necessity, determining the product pre-requisites and restrictions, defining the purpose of the product, investigating the state-of-the-art and determining the principles of solution.

The **Preliminar Design** is responsible for defining the specifications of the product, materials, identification of the product or service components and fitting process, economic viability, selection of the principle of solution and ergonomic analysis.

The **Product Archicture** (Design Assessment and Improvement) is responsible for analyzing product dimensions, identifying the basic and secondary purposes of the product, selecting the manufacturing processes and overall drawing.

The **Detailed Design** (Prototyping and Final Design) involves studies to reduce costs and avoid any unnecessary cost before manufacturing the product, and detailing the overall design. In this stage, prototyping can be made with physical or digital scale models for a 3-D view of the product. Prototyping contributes to potential overall design changes, ergonomic reassessment, product detailing, manufacturing process planning, assembling and packing planning.

Before starting the design, students were divided into groups of 6 members (design team) and discussed this methodology with the teacher. Thus, each group was responsible for conducting their own design. At the end of each stage, group seminars were held with the presentation of their results, generating a discussion forum, where a manufacturing setting was simulated in which the development of a new product was the fruit of team work. At the end, each group was required to make a more formal group presentation.

Examples of *rapid design exercises* are described in [2] and [3] showing the applicability of the object as a means to provide orientation for the development of the product or service.

COMPUTER SUPPORT FOR THE DESIGN PROCESS

In product the design process, the previously described activities result in technical documentation of the designing process, classified according to the information of each stages. Drawings and texts are the most common forms to represent information. Along their creation process, they are the most common means of communication serving as referential and language documentation for the planning of the manufacturing and assembling process.

During the semester student's reports and other academic activities are all managed through computer information systems. These systems are usually accessible from the Internet and make a mean of record and assessment of the design in progress. In the case reported here the students used this computer support as a tool for provide and record the communications among team's members; bring new information resources for the tasks in hand, platform for development and storage of teams work.

Soibelman & Caldas [7] identify a series of document formats used during the development of a project (Table 1).

TABLE 1
DOCUMENTS USED IN PROJECT DEVELOPMENT. SOURCE: ADAPTED OF SOIBELMAN&CALDAS [7].

Documents	Content	Application Examples
STRUCTURED DOCUMENTS	➢ Files processed through database	➢ Budget control ➢ Purchases/financial control ➢ Database for budgets elaboration
SEMI STRUCTURED DOCUMENTS	➢ Stored in HTML, XML or DWF format files	➢ Drawings web file (DWF) ➢ Hypertext interlinking information from different documents or from itself ➢ Companies websites ➢ Government entities to effective norms/legislation
NOT STRUCTURED DOCUMENTS	➢ Filed as text, sheets or in specific software	➢ Specifications, spreadsheets, contracts. ➢ Mail messages, forums and chats ➢ Organization charts and flowcharts from specific software
GRAPHIC DOCUMENTS	➢ Stored in CAD system applications	➢ Drawings in CAD files, in 2D and 3D, such as drawings in DWG, DXF.
MULTIMÍDIA DOCUMENTS	➢ Stored as images, audio or videos	➢ Pictures ➢ Audio messages ➢ Video or audio meetings

A design team is an ensemble of experts in several domains cooperating in a common goal that needs a sort of functionality to enhance their work. The design arena, a place to set up collective activities, is much more an environment for negotiation of conflicts and decision making, where the identification of the tasks and the relationships between them allow tackles the domains and the role to be played by each participant. The routine issues addressed in supporting a team are how to manage and control the design information state, how to share the correct information and how to deliver design information in the correct time [8] [9].

Some of these key concepts of the Concurrent Engineering are adopted in the discipline project. There are examples like the work with only one virtual artifact that is being constructed along the design process and allows the share of data, information and knowledge among the team members in a simple and fast way. This approach leads to a more precise management of the process [5].

PROJECTS DEVELOPMENT

As in any design process it is started from an individual or collective necessity, the result of a market research, among others. In the experience reported here there were no space for a more deeply field survey leading to some strategies adopted in the discipline. The search for the consumer needs was made from a seminar and a debate among students and the teacher.

Among the previously selected ideas the teams started the viability studies. The transformation of those ideas into product concepts includes the evaluation abut form, function, target and benefits of the product or service [6]. In the case of the didactic experience constrains were established by the teacher due to the lack of a real life environment.

There were also realized some benchmark research trough an Internet survey in intellectual property databases - INPI in Brazil and USPTO for the United States and Europe. There was also some research on the Internet in the similar products sites and visits in the local market.

The students also used the QFD (Quality Function Deployment) for the data analysis from those surveys.

The figures 1 and 2 show two of the products developed by the teams. The figure 1 represents the mechanism studies for a product name toothbrush “2 in 1” that was a result of viability analysis among other selected ideas. During the seminars some other alternatives were found mainly in the handler of the toothbrush. These were the injection of the dental gel trough a piston; the head of the toothbrush adapted to a tooth paste tube trough a thread; handler that can be pressed, among others. From the studies presented in the figure 1 the team adopted the development of a mechanism for the tooth paste injection in the head of the toothbrush.

The figure 2 represents a product called “Ideal Stair Chair” that has double function as a simple chair and a stair of low range for residential use. The figure 3 shows a diagram intended to guide the development of software named “Electronic Menu”. The primary benefits though by the student’s team were the reduced waiting and delivering time by the client’s side trough the agility in the delivery of food and drink since the orders arrives in real time to the kitchen. The secondary benefit is on the owner’s side with optimized processes since the information needed for diverse tasks are always in hand.

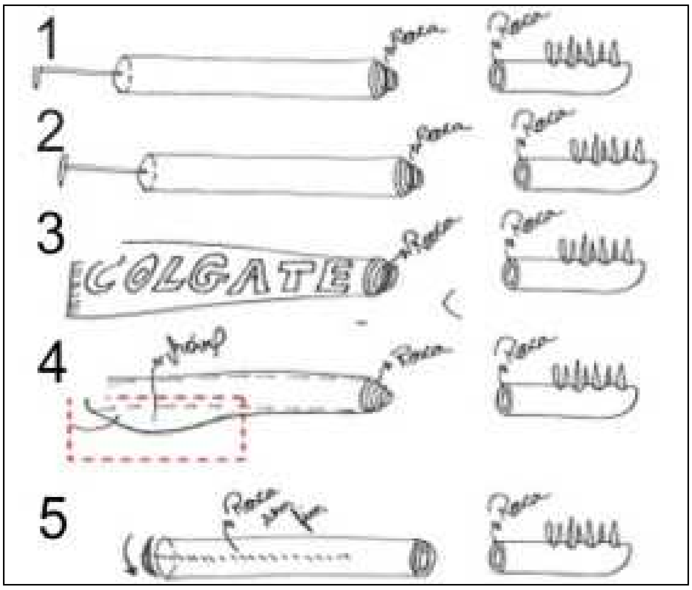

FIGURE 1
TOOTHBRUSH STUDIES WITH THE DIVERSE ALTERNATIVES GENERATED. 1)FIXED PISTON, 2)MOVABLE PISTON, 3)ADAPTED HEAD, 4)FLEXIBLE HANDLER AND 5)ENDLESS THREAD

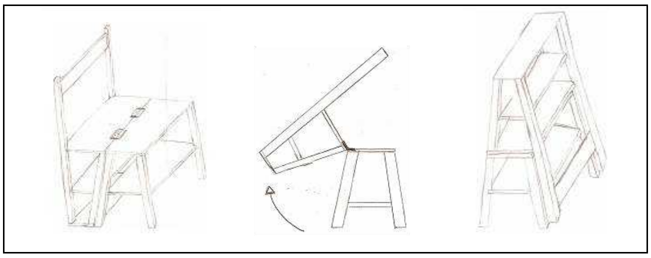

FIGURE 2
BASIC CONCEPT OF THE “STAIR CHAIR” DESIGN

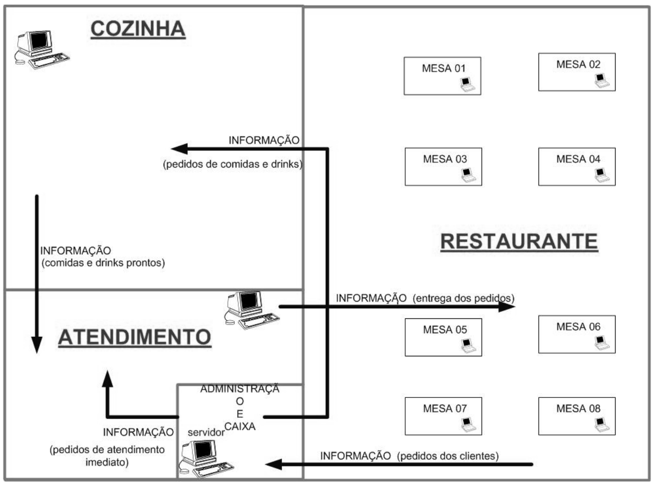

FIGURE 3
FLUX DIAGRAM FOR THE ELECTRONIC MENU.

For the “Electronic Menu” development the proposal was built in simulated environments incorporating the following solution principles:

- Product setting – the product will be fixed in a support under the table with the screen leveled with the table top.
- Support material – finished aluminum sheet.
- Support method – mechanic union (screws and nuts)
- Interface with the client – Palmtop pen.

- Operating mechanism – pressing the palmtop pen in the desired item.
- Screen protection – thin layer of translucent film with good mechanical resistance and hardness.
- Security system – if there were a disconnected cable the system emits a sound alarm.
- Sound options – must be made to the waiter and the music choice will be automatic.
- Hardware needed: table palms, main computer, waiters screens, kitchen screens, keyboards, among others.

One of the integration among disciplines in the course is related to the ergonomic aspects of the products developed. There is specific software used in the Ergonomics discipline that allows for a better dimensional approach of the solutions. It is also used the "ErgoKit" developed by the design department at the Brazilian Institute of Industrial Property (INPI). This kit is composed by tables with variable body values and mannequins in 1:5 scales that allow the simulation of operator's body movements in the workplace.

There is also used CAD software to support the design process and its representation allowing the designer to verify diverse aspects of the solutions being adopted in two or three dimensions, including the assembly verification. There was also used 3D modeling software to analyze diverse aspects of the final solutions.

In the experiments reported here there were used alternative materials for the prototyping of the "Ideal Stair Chair" design. In the case of the toothbrush design there was used a similar product with other functioning principle to model a prototype of the final solution. For the "Electronic Menu" design the team used CAD software to draw the final flux of the service. These prototypes are presented in the figures 5 and 6.

FIGURE 5 – PROTOTYPE OF THE 2 IN 1 TOOTH BRUSH DESIGN

FIGURA 6 – "IDEAL STAIR CHAIR" PROTOTYPE.

ADDITIONAL CONSIDERATIONS

The experiences reported here provide students with an opportunity to conceive a product and implement it, using simple development and rapid sketches methods. Introduction to this exercise the class will cover the design process, problem solving methods, interdisciplinary team work, current industrial practice, manufacturing process capabilities and physical prototyping.

As a directly collaborative dimension, an virtual environment for the support of product design teaching and learning processes, named Design Knowledge Database (DKD), has been used to as a cooperative work tool that allows the tracking of the design process.

The DKD is structured around three main modules that are connected by an association's tool. The first module is related to the explicit knowledge incorporated in the design activities and is represented by a dynamically constructed database. The second incorporates a case-based library related to the implicit knowledge that came from the user's experiences and also from the design tasks that are being developed by the students or teachers. The third module deals with the implicit knowledge that came from the association of case based library and projects in development with the personal knowledge of each one that is involved in the design process. It intends to capture this kind of personal knowledge allowing the user to formalize how some specific task can be done or how to perform some procedure related to, for instance, what the team is doing in the moment. This module can also keep some registers of methodologies and practices of the product development that can't be classified in a more formalized and classified way in the first module.

In that sense, the student's teams can access the design solutions of early semesters and the ones being developed at the same time.

This and other cooperative work environments were developed by some of the researches at the Production Engineering Department and are described in [9] and [2].

FINAL CONSIDERATIONS

The experiences reported here aims to guide the students through a mix of theory, application context and practice of the product development process. In that sense the discipline was able to generate the conditions that allow its students to look at the current business landscape from a systemic and integrated viewpoint that is necessary for the development of any type of innovations in products and services.

It is clear that is impossible to bring to the academic context all the complexity and variables of real life product development process. What is intended and achieved is to lead the students to a perspective more close to this reality considering both the support tools and the methodologies of product design. In this way the teachers aims to prepare those future professionals in what can be one of the most challenging tasks in the university: learn to learn.

The product design process offers a good opportunity to exercise that task. It frequently faces the designers with the need to solve problems that aren't clear or explicit in the beginning of the process. Also these problems can be from a diverse universe of competences and one of those future engineers' challenges is to conciliate and manage those knowledge areas.

Also is important to emphasize one important aspect of that learning and teaching process. The use of web based tools such as the DKD that has an academic profile and other communications tools has enhanced the learning curve as those are closer to the student's universe and practice. They have a good familiarity with the resources available in the DKD for instance. Of course there is a lot of work to do and the next directions of the research are to achieve a more precise evaluation of these tools utilization.

However, one can argument that the learning and teaching process quality depends more on the use, on the didactic exploration and on the context where this process takes place, than on the technical characteristics and on the technological means.

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