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Do We Have an Alternative Methodology for Teaching Design?
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Abstract
The study reported here is a research project aimed to examine the relationship between alternative approaches towards design teaching (structural or functional), and the students' mental modelling of the design process and the quality of their design process. The structural approach emphasizes the need for an ordered learning of the stages of the design process, while the functional approach emphasizes the teaching and study of design functions (rather than stages). 80 seventh graders, divided in two groups, were taught a unit on technological problem solving by either approach for fourteen classes (21 hours). Before, during and after the design process of a technological solution the students had to generate representations of this process and make portfolios representing their problem solving process. The results were analysed looking for:
(a) The differences between the groups in the mental models which were constructed during the instruction process.
(b) The differences between the groups in the quality of the process and the design functions implemented.

Significant differences between the groups observed for many of the variables studied indicate that the functional approach represents a promising methodology for teaching design.

Key words: design process, design functions, design teaching, mental models.

Significant changes have taken place in technology education in the last decade. Educators and educational policy makers have become aware of the importance of technological concepts and skills as essential part of education. The contents, skills, and methods of technology education are being re-examined, regarding both technological literacy and specialization studies.

One of the major goals of technological literacy is to provide students with tools for solving technological problems. The main methodological resource for this purpose is the design process, as used by technologists and designers to create solutions in response to human needs and enhance the quality of life. There is a conflict regarding the nature and qualities of the design process: on one hand, it is conceived as a creative, branching, and cyclical process based on multi-disciplinary knowledge, while on the other hand it has to meet the requirements of products-production processes, e.g., to be structured, to proceed in stages, to meet schedules, to be clearly product oriented.

Signs of this conflict can be found amongst researchers and educators consideration of two alternative approaches for teaching the problem solving process: the structural (step-by-step) approach, and the functional approach. The structural approach emphasizes the need for an ordered learning of the stages of the design process. This approach is the one commonly implemented in curricular materials, and many studies have focused on it. The studies' results raised doubts about the capability of the students to achieve a holistic view of the process and to construct an appropriate mental model of it, by this instructional approach (Hennesy & McCormick, 1994; De-Vries, 1997).

The functional approach emphasizes the teaching and study of design functions (rather than stages), such as: problem identification and definition, investigation, decision-making, planning, making, evaluation. At every stage of the design process the student may implement one or several design functions (e.g., the functions 'search for information' and 'evaluation' may serve the definition of the solution requirements and constraints, and later on in the process the generation of alternative solutions). According to this approach the problem solving process is expected to be a flexible and cyclical one. The instructional plan is based on the teaching of the different design functions (Chidgey, 1994; McCormick, 1997; Mioduser, 1998;), for the students to use them in the way that best matches the problem, the particular stage in the process, and their own personal style. In contrast with the structural approach, for the functional approach very few attempts to develop instructional materials have been made. (Johnsey, 1998; Hill, 1998;) and only a few studies have been conducted.

The aim of the study reported in this paper is to identify the relationship between the instructional approach, the mental models constructed by the students and the problem solving processes actually
taking place. Our research questions focused on the examination of the relationship between learning design in either of the two instructional approaches (structural and functional) and:
1) The students’ mental models of the technological problem solving process.
2) The patterns of use of the various design functions by the students while designing a solution.

Method
The research population comprised 80 seventh grade students, in mixed ability classes with equal number of boys and girls, learning design as part of the compulsory science and technology curriculum. Students were divided into two groups. One learned the design process in the structural approach (stages group) and the other in the functional approach (functions group).

By both instructional approaches the students had to identify a problematic situation, define the problem, the needs, and the requirements for the solution. In the structural approach the students learned the design process stage by stage, implementing one stage at a time until completing the solution. In the functional approach, the students defined the problem, requirements and constraints and then learned the whole set of design functions which they implemented in varying configurations according to their decision during the design process. After solving their own problem during the learning process, both groups were given a new problem to solve. The instruction lasted for fourteen meetings, 90 minutes each.

As regards to the data collection and analysis several instruments were developed: For the first question dealing with the students’ mental models we analyzed representations of the process as drawn by the students (Figure 1) on six occasions: prior to the learning, three times during the course of learning, at the end of it, and once again about the new problem. Those drawings was collected for each student in a ‘carpet’ (Figure 2) and analysed by several criteria that will be described in the results description. For the second question on the patterns of use of the design functions we examined student portfolios (1) which were developed during the problem solving process; and (2) which were developed while solving a new problem. For the third question on the quality of the solutions generated, we examined drawings and models built by the students.

Finite Linear Model:

Cyclic Linear Model:

Branching Model:

Figure 1: Representations of the process as drawn by the students (the type of their models)
Results

Question 1: On the relationship between the instructional approaches (structural and functional) and the students’ mental models of the design process.

From the reports created by the students at six points in time (before, three times during, and at the end of the learning, and for the solution of a new problem), we created a profile of the development of the mental model of the design process for each student. The analysis of the data resulted in the following three variables for the characterization of the models:

Types of models of the design process
Four types of models were identified:
(a) Sequential-linear model;
(b) Cyclical-linear model;
(c) Branching model; and
(d) Narrative/descriptive model.

Changes in type of model during the learning process
Two aspects were examined:
(a) Number of students who changed type of model along the learning; and
(b) Changes in type of the model per student.

Characteristics of the student mental models
Four characteristics were identified:
(a) Frequency of use of the different design functions;
(b) Recurrent use of design functions;
(c) Differential use of divergent and convergent design functions; and
(d) Level of complexity of the process.

In Figure 2 the findings for the above variables are presented. The mental models of the stages group showed equal distribution for both the sequential-finite and cyclic models; only few changes occurred during the learning and after it; the students used only few design functions; they used as whole set first convergent and then divergent functions separately; the representations are less complex and have only few iterations of design functions.
In contrast, the mental models of the functions group are mainly sequential-finite; there are many changes during the learning and after it; students used many different problem solving functions; many transitions between convergent and divergent functions were observed during the learning; their models are complex and have a great deal of iterations of design functions. Significant difference was found between the research groups (stages and functions) in the aspects of the student mental models of the design process included in Figure 3.

Question 2: On the relationship between the instructional approaches (structural and functional) and the scope and quality of use of the design functions by the students

Data collection for this question was based on the analysis of the student portfolios for: (a) the authentic problem, identified by the students during the thirteen sessions process, and (b) a new problem, in a limited 90 minutes session. The analysis resulted in a set of variables regarding to three main groups of skills or processes: designing, thinking and making. Examples of skills from the ‘designing’ category are: problem description, identification of needs, specifications definition, review of resources, documentation generation. Examples of skills pertaining to the ‘thinking’ category are: making connections between features of the problem and resources reviewed, evaluation of alternative solution paths, planning the solution. Examples of ‘making’ skills considered are: drawing and use of notations, model building.

In Figures 4 and 5 selected findings resulting from the analysis of both groups’ students portfolios are presented (only for the variables for which significant difference between the groups was found).
<table>
<thead>
<tr>
<th>Process variables</th>
<th>Stages group</th>
<th>Functions group</th>
<th>Difference</th>
<th>t value</th>
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<td>Designing skills</td>
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<td></td>
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<tr>
<td>Problem definition</td>
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<td>3.5</td>
<td>0.4</td>
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</tr>
<tr>
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<td>2.0</td>
<td>0.5</td>
<td>-2.14*</td>
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<tr>
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<td>7</td>
<td>0</td>
<td>3</td>
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<td>Review/survey</td>
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<td>1.0</td>
<td>0.8</td>
<td>5.67**</td>
</tr>
<tr>
<td></td>
<td>0</td>
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<td>2</td>
<td></td>
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<tr>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Investigation/problem</td>
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<td>3.2</td>
<td>0.8</td>
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<td>connection</td>
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<td>3.7</td>
<td>1.2</td>
<td>-3.46**</td>
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<td>0</td>
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<td>2</td>
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<tr>
<td>made</td>
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<td>3.1</td>
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* p<0.05  ** p<0.01

**Figure 4**: Mean quality of use of selected design skills (with significant difference between the groups’ means) as observed in the student portfolios along the learning
During the instructional process the stages group showed better performance than the functions for two variables only: ‘problem definition’ and ‘performs a survey’, both belonging to the designing skills. The functions group showed higher mean scores in many variables which belonging to all categories during the instructional process and while solving a new problem as well. Specifically, students who belong to the functions group, performed at a high level for variables related to high thinking processes and interactions between functions (e.g. connection between the information gathered and the problem features).

Significance difference between the groups was found also in the scope of actual use of the design functions. In the functions group, 78% of the students used 7-10 functions, while in the stages group 65% of the students used 2-6 functions and 35% used 7-8 functions. These findings suggest that the functions group reached greater flexibility in using the functions, and a better understanding of both the overall structure of the design process and the contribution of particular functions to this process.

**Discussion**

In technology education, a significant gap regarding the way the teaching of the design process should be devised can be recognised. In one hand, most curriculum developers and practitioners implement the traditional algoritmic, step-by-step and systematic approach as main instructional methodology. In the other, a critical examination of the structured approach by several researchers (Hill, 1998; Johnsey, 1998; Chidgey, 1994; Kimbell, 1997; Hennessy & McCormick, 1994;) has conduced to the development of a different approach focusing on a ‘design functions tool kit’ (Hennessy & McCormick, 1994; Mioduser, 1998, Hill, 1998; De Miranda, 2004).

The purpose of this study was to examine the ways these two approaches (the structural, which we know more about it; and the functional, which we know very little about) affect the learning of design. In it we compared both instructional approaches as regards to:

- The development of mental models of the design process.
- The quality of the design processes by students.
The development of mental models of the design process

Instruction in the functional approach contributed to the development of flexible, efficient, iterative mental models like those of expert designers (Cross, 2002; Lawson, 1997; Bucciarelli, 1994). This approach encouraged the students to reflect on the process and its purpose, in order to decide what should be the next step. During that, they gradually completed their image of the process and the solution in dynamic and active way, constructed and reconstructed holistic and runnable mental models of the problem and its solution (Hegarty, 1991; Norman, 1983; Kieras, 1988; De Miranda, 2004). As opposed to this, and as found in many other studies, in the structural approach the students were taught each time a stage of the ‘right’ model, while the students’ alternative models were discarded. In consequence they constructed in every lesson a partial image of the process, (Hennessy & McCormick, 1994; McCormick, 1997; Chidgey, 1994;), an inefficient problem solving mental model.

The quality of the problem solving/design processes

The performance of the structural approach students is similar to what was found in other studies: they performed every step as an activity they had to accomplish with no reference to the overall process (Hennessy & McCormick, 1994; Jones, 1997). In this group the scope of usage of design functions was limited, and they used just the ones they needed to follow the teacher requirements and the assessment demands, like novice designers (Hennessy & McCormick, 1994; Cross, 2002). In contrast, the functional approach instruction led the students in the functions group to develop a holistic perception of the design process, and to a rich and flexible use of diverse design functions.

A particular aspect of the process worth mentioning relates to the building of working models of the designed solutions by the students. Students in both groups lacked necessary skills for the successful accomplishment of the task (e.g., technical-drawing ability, building skills). Notwithstanding, more students in the functions group (than in the stages group) built models, suggesting that they perceived this stage as integral part of the design process, as the point at which the whole set of ideas and activities of the previous segments of the process converge.

As overall conclusion, in most of the aspects studied the functional approach was found more supportive of profound and comprehensive learning of the design process than the structural approach. In addition, we suggest that specific aspects that characterized the stages approach (e.g., structured planning of each stage and its local goals, definition of evaluation criteria for assessing each stage’s accomplishments) should be integrated within the functional approach. By this we aspire to devise a model of design instruction that is both a profound and efficient pedagogical solution.

References


