The effect of alternative approaches to design instruction (structural or functional) on student perceptions of technological problem solving processes

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Abstract

The study reported here is part of a larger 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 solutions to design tasks. The structural approach emphasises the need for an ordered learning of the stages of the design process, while the functional approach emphasises 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 14 classes (21 hours). Before, during and after the design process of a technological solution the students had to generate representations of this process. The results were analysed looking for:

a) the types of models of the design process constructed by the students
b) consistency in the configuration of the design functions included in the models over time
c) internal logic and coherence of the configuration of functions in the models
d) recurrent use of design functions in different stages of the solution-generation process.

Keywords

problem solving, mental models, design, technology education, junior-high school

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 part of today's education of citizens. The contents, skills, and methods of technology education are being re-examined, regarding both technological literacy and specialisation 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 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: in one hand, it is conceived as a creative, branching, and cyclical process based on multi-disciplinary knowledge, while in 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 dealing with technology literacy. There are two methodological approaches for teaching the problem solving process (Polya, 1957; Newell and Simon, 1972; Schon, 1983; Charles and Lester, 1984; Philpot and Sellwood, 1987; Todd, 1990, Hegarty, 1991; Hutchinson and Karanitz, 1994; Kimbell, Stables, and Green, 1996):

a) the structural (stage-by-stage) approach, and
b) the functional approach.

The structural approach emphasises the need for an ordered learning of the stages of the design process (Hutchinson 1994, Todd 1990, Waetjen, 1989). Different models (differing from each other mainly by the number of stages into which the process is divided) were developed all over the world for teaching design as an organised and methodical tool (e.g. DES in UK 1989, in the US, Australia, Argentina, the Nederlands). The learning process proceeds as the gradual implementation of the different stages.

The functional approach emphasises the teaching and study of design functions (rather than stages): problem identification and definition, investigation, decision making, planning, making, evaluation. At every stage of the process the problem solver may use more than one of the design functions (e.g. investigation and evaluation). According to this approach the process of problem solving is expected to be more flexible and cyclical. The instructional plan is based on the teaching of the different design functions (Chidgey, 1994; McCormick, 1994; Mioduser, 1998), so that the students will use them in the way that best matches the problem, the situation, and their own personal style.

The structural approach is more 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 by this instructional approach (Hennesy and McCormick, 1994; Johnson, 1994; de-Vries, 1997). In contrast, for the functional approach very few attempts for the orderly development of instructional materials have been made, (Johnsey, 1998) and only a few studies have been conducted.

A central goal of design-process instruction is to allow the construction of appropriate mental models of the technological problem solving process, in the form of internal representations of the real world situation and its solution (Barker *et al*, 1998). By mental design models we refer to systematic structural/functional/causal internal models of the design process (Mioduser, 1998). We still lack appropriate research knowledge of mental models construction by students while learning design in both of the above approaches to design instruction.

The study reported in this paper is part of a larger research aiming to identify the relationship between the instructional approaches, the mental models constructed by the students, and the problem solving processes actually taking place. Our overall question focused on the examination of the connection 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 scope and quality of use of the various design functions by the students while designing a solution; and
3) the components and quality of solutions for different problems as generated by the students.

From amongst these questions, we report in this paper on preliminary results related to the first research issue: The connection between the instructional approach (structural or functional) and the students' mental models of the technological problem solving process.

Method

The research population comprised 80 seventh grade students (junior-high school), from Ort School in Akko (northern Israel), learning design as part of the compulsory science and technology curriculum. The students learn in heterogeneous classes in which there are an equal number of boys and girls. The participant students pertain to four classes, which for this study were divided in two groups:

- two classes in which the design process was taught using the structural approach
- two classes in which the design process was taught using the functional approach.

In both instructional approaches, the students had to identify a problematic situation, and define the problem, the needs, and the requirements for the solution. In the structural approach the students learned the design process stage after stage. At each stage they studied what they have to do and applied it to the problem they had chosen. In the functional approach, the students defined the problem, the needs and requirements and then learned all the design functions (tools). We emphasised the fact that it was possible to make use of different functions in different places in the process, and more than once.

After solving their problem (during the process of learning), all the students in both groups were given a new problem that they were asked to solve – to design and model it.

The participant teacher was selected on the basis of his ample experience of several years' in teaching problem solving in junior-high school. The instruction lasted 14 meetings, 90 minutes each.

The research tools

In this research we used two groups of research tools, qualitative as well as quantitative tools. Qualitative/interpretative tools were used in order to identify and examine processes as they were taking place. We used models of the process as drawn by the students on different occasions: prior to the learning, three times during the course of learning, at the end of it, and once more about a new problem. The collected data was organised and analysed in order to construct profiles of the development of the students' models of the design process. Quantitative tools were used to examine whether the differences within and between the groups were statistically significant.

Findings

Qualitative analysis of the student models

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 problem solving process for each student. The analysis of the data resulted in the following four categories for the characterisation of the student models.

1. The types of models of the design process constructed by the students.

Four types of models were identified:

- A finite linear model: The students described the problem solving process as a series of stages/functions ordered in a linear manner.
- A cyclic linear model: The students described the problem solving process as a series of stages/functions which include return paths to previous stages/functions.
- A branching model: The students described the problem solving process with many branching nodes.
- In addition some students described the problem solving process only verbally, without any graphical representation of it.

2. Consistency in the configuration of the design functions included in the student models over time.

The student models were divided into three sections (i.e. beginning, middle, and end of the design process). The subsets of functions included in these sections, and their configuration were identified. Consistency among models over time was examined resulting in the following categories: Full consistency (of most subsets of functions along all models), partial consistency (mainly for the beginning and final section of the design model, but discontinuous for the middle section), and no consistency at all.

3. Internal logic and coherence of the configuration of functions in the student models.

The logic and coherence of the models was considered according to the following criteria:

- in the first section of the process the following functions are expected (order is unimportant): identification of the problem, generation of ideas, investigation and graphic representation
- in the second section of the process the following functions are expected: investigation, graphic representation, solution-selection, evaluation, and detailed design. Detailed design is expected to follow solution-selection (the order of the other functions is unimportant).
- in the third section of the process the following functions are expected: evaluation and construction (order is unimportant).
- investigation and evaluation can appear anywhere in the process.

The following are examples of configurations that violate internal logic:

- in the first section of the process evaluation or construction appear before any other function, or identification of the problem is absent
- in the second section of the model detailed design appears before solution-selection
- in the last section of the process ideas-generation, identification of the problem, or graphic representation or solution-selection appear after construction.

4. Recurrent use of design functions.

The fourth category of analysis focused on the repeated inclusion of certain design functions in different sections of the models of the design process. The most frequently included functions, and their locations, were identified in the student models.

Quantitative analysis of the student models
As a result of the qualitative analysis stage, we characterised the set of models built by every student, quantified the diverse aspects of these profiles for all students, and compared the results between groups, as described in the following sections.

1. Type-of-model distribution by groups.
Table 1 shows the distribution of the diverse types of model for the participating groups, during the learning process and for the new problem.

	Learning process		**New problem**	
	Stages group	Functions group	Stages group	Functions group
Without a model	4	15	7	15
Finite linear	47	62	37	76
Cyclic linear	40	15	48	9
Branching	9	8	7	
	100%	100%	100%	100%

Table 1: Distribution of types of model for both groups (percentage of students).

	Consistency during the learning process	Consistency between the last model and a new problem
Stage group	1.85	1.92
Functional group	2.09	2.52

Table 2: Consistency among models (group average).

The stages group (both during the learning process and in the new problem) generated mainly finite linear models and cyclic linear models, while in the functional group most of the students built finite linear models. More students in the functional group did not represent graphically the process than in the stages group.

2. Consistency among models along the learning process.
Table 2 shows the average level of consistency (on a scale of 3) among configurations of the design functions in two points in time: among models generated during the learning process, and between the last model in the learning stage and the one generated for a new problem afterwards.

Although no significant difference was found between the groups, it can be seen that in the functional group there is greater consistency than in the stages group, both during the learning process and for a new problem.

3. Internal logic and coherence of the models.
Data related to the internal logic and coherence of the models generated by the students in both groups along six points in time is presented in Figure 1.

For the stages group, there is an increase in number of internally coherent models from the first model (26%) to the fifth model (40%) during the learning process, where the largest number of these appears for the second point in time (50%).
For the functional group we also see an increase in the number of internally coherent models, but a less significant one: from 26% of the models in the first point in time to 30% in the fifth. The largest number of these models were generated in the fourth point of time (45%).

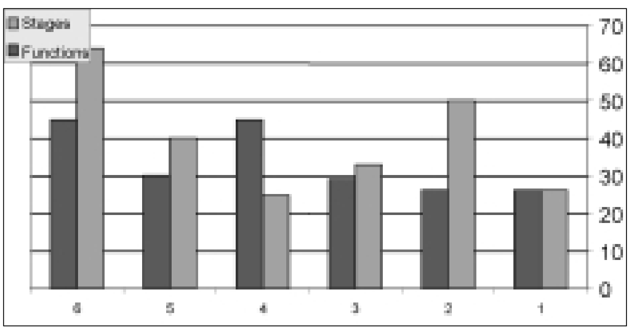

Figure 1: Internal logic and coherence of the models (percentage).

For most of the learning processes, more internally coherent models were generated by students in the stages group, and the number of these increased as regards to a new problem for both groups (64% for the stages group and 45% for the functions group).

4. Recurrent use of design functions.
The extent to which the students included repeatedly certain design functions in different stages of the generation of the solution is summarised in the following:

1) in the stages group 11% of the students used the same function more than once in a specific model, and in the functional group 47% of the students did so
2) in the stages groups 33% of the repetitions are of more than one function. In the functional group 38% (sometimes repetition of four of five functions).
3) regarding a new problem, the stages group did not include repetitions. In the functional group 15% of the students did. One of the students repeated the same function three times (investigation) while the rest used the same function twice.
4) in the functional group most frequent repetitions were of the functions: investigation 60%, evaluation 20%, and choosing a solution 20%.

Discussion
The study reported here is part of a larger 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 solutions to design tasks. In this report we present preliminary results focusing on the students' representations of the design process along several points in time prior, during and after the learning process. Based on this preliminary analysis of the results, we can identify the following trends:

1 We can see that the instructional process itself (regardless of the approach) influences the mental modelling of the problem solving process. In both groups we found an increase in the internal logic and coherence of the generated models over time.
2 The stages group learns the design process in a very orderly manner. Consequently, immediately

after the second lesson it is possible to see an increase in the number of internally logical models, up to the end of the process. In contrast, in the functional group, the students construct by themselves the most suitable method for solving the problem. In other words, they learn while trying out different options and thus only from the fourth model on we could see an increase in the number of internally logical models (according to our defined criteria).

3 In the functional group most of the students use a finite linear model, although they learned in a way that permits greater flexibility. In contrast, the stages group uses both the finite linear model and the cyclic linear model (to an equal extent).

4 We expected that in the functional group there would be more recurrent use of the different design functions at different stages of the solution generation process, and in fact this was the case.

The results of the whole study are currently being analysed. At its end, we expect to unveil the underlying cognitive processes characterising the generation of design solutions in both groups, as well as the way these solutions were affected by the alternative approaches towards design instruction.

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Note

The reported work is part of the first author's PhD dissertation in Tel-Aviv University's School of Education, under the second author's supervision.