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ORIGINAL PAPER

The effect of alternative approaches to design instruction (structural or functional) on students' mental models of technological design processes

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Abstract The study aimed to examine the relationship between alternative approaches towards problem solving/design teaching (structural or functional), students' mental modeling of the design process, and the quality of their solutions to design tasks. The *structural* approach emphasizes the need for an ordered and systematic learning of the design process stages, while the *functional* approach emphasizes the teaching and study of design functions (rather than stages). Participants were 80 seventh graders, divided into two groups, who were taught a unit on technological problem solving by either approach in the course of 14 classes (21 h) during a semester. Before, during and after the design process of a technological solution the students represented their perception of the design process. The results for both groups were analyzed in terms of: (a) types of models generated; (b) changes in type of models along the learning/design process; (c) defining characteristics of the design process models. Significant differences between the groups' models were found for most variables examined. The functional approach was more effective than the traditional structural approach for supporting the construction of holistic, flexible, and effective mental models of the design process of technological solutions.

Keywords Design process · Design functions · Mental Models · Technology Education

Significant changes have taken place in technology education in the last decade (DES, 1989; ITEA, 2000; Kimbell, 1997). Educators and educational policy makers have become aware of the importance of technological concepts and skills as central components of today's citizen's cultural background. As a consequence, the contents, skills, and methods encompassing technology education are being re-examined, regarding both technological literacy and specialization studies (Johnsey, 1998; Kimbell, 1997; McCormick, 1997; Mioduser, 1998). Common to most curricular proposals is the focus on the design process

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of technological solutions as the central methodology in technology. However, diverse approaches towards design instruction have evolved (e.g., structural, functional—a detailed discussion on these and others appear in the background section) though the study of the effect of these different approaches on the learning of design is still in its early stages.

In this paper we report on a segment of a long-term study focusing on the acquisition of technological problem solving methods and skills by junior-high students participating in a technological literacy course. During the course, the students were actively involved in designing a solution for a technological problem. Here we will focus on the students' cognitive modeling or mapping of the design process, as a function of diverse instructional approaches towards design.

Background

Problem solving instruction in technology education

One of the major goals of technological literacy is to provide problem solving capabilities and skills to the students. The main pedagogical resource for attaining this goal is to engage the students in design processes as practiced by technologists to create solutions in response to real-life needs. Theoretically, there is a conflict regarding the nature and qualities of the design process: on one hand, it is conceived as a creative, branching, iterative, and cyclical process based on multi-disciplinary knowledge, while on the other 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 technological literacy. Overall, most curricular proposals can be classed into two main approaches for teaching the problem solving process: (a) the structural (step-by-step) approach, and (b) the functional approach (Hegarty, 1991; Hutchinson & Karsnitz, 1994; Johnsey, 1998; Kimbell, Stables, & Green, 1996; Mioduser, 1998; Polya 1957; Schon, 1983; Todd, 1990).

The *structural* approach emphasizes the need for an ordered learning of the stages of the design process (Radcliffe & Lee, 1989 in Cross, 2002; Hutchinson & Karsnitz, 1994; Todd, 1990; Waetjen, 1989). Different models (differing from each other mainly in terms of the number of stages into which the process is divided) were developed all over the world for teaching design as an organized and systematic process (e.g., in UK: DES, 1989; in the US: ITEA, 2000; in Australia, Kimbell, 1997.; in Israel: Science and Technology Syllabus, 1996). The learning process proceeds as the gradual implementation of the different stages.

The *functional* approach emphasizes the teaching and study of design *functions* (rather than stages): issues identification and definition, exploration and investigation, decision making, planning, making, and evaluation. At every stage of the process the problem solver may use more than one of the design functions (e.g., investigation and evaluation), depending on the specific context and requirements of the particular stage. For example, the *investigation of alternative knowledge resources* function will take different form and goals whether it is applied for defining the design goal or for scanning alternative solution paths. Thus, *function-contextual-traits* are the basis for every activity implemented during the solution generation process (Dagan, 2005, unpublished doctoral dissertation). On this approach the process of problem solving is more flexible and cyclical. The instructional plan is based on the teaching of the different design functions (Chidgey, 1994; Lawson, 1997; McCormick, 1994; Mioduser, 1998), so that the students will use them in the way that best matches the problem, the situation, and their own learning and working style.

The structural approach is the one more commonly implemented in curricular materials, and many studies have focused on it. These studies' results raised doubts about students' ability to achieve a holistic view of the process by this instructional approach (De Vries, 1997; Hennesy & McCormick, 1994; Johnson, 1994; Jones, 2002; Mawson, 2003; McCormick, 1997). In contrast only very few attempts have been made to develop instructional materials for the functional approach, (Johnsey, 1998; Mawson, 2003) and studies concerning this topic have rarely been conducted (Hill, 1998; Mawson, 2003).

Mental modeling of the design process

A central goal in design-process instruction is to support the construction of appropriate mental models of the technological problem solving process. These models are in fact internal (cognitive) representations of the real-world situation, the problem associated with it, the process activated for generating a plausible solution, and the solution itself (Barker et al., 1998). By design-mental-models we refer to systematic structural/functional/causal cognitive models of the design process (Mioduser, 1998). Research knowledge on design-mental-models is scarce. Most research related to mental modeling in technology relates to (a) people's understanding of the way technology systems work; and (b) their use of, and problem solving with, these systems (DeKleer & Brown, 1981; Halasz & Moran, 1983 in Kieras, 1988; Hegarty, 1991; Kieras, 1988; Norman, 1983; White & Fredriksen, 1986). The main findings in these studies indicate that students who possessed an appropriate structural and functional mental model of a given system used it for designing and planning effective solutions to problems related to the system's functioning or operation (Kieras, 1988) and troubleshooting (White & Frederiksen, 1986). These models assisted people in producing sound causal explanations (White & Frederiksen, 1986) and in making predictions about novel situations not yet examined (Kieras & Bovair, 1984).

Research on novice/expert problem solvers also stresses the role of mental models in characterizing design performance at the different levels of expertise. The expert problem solver is assumed to possess powerful, dynamic and flexible mental models which adapt to different contexts and improve over time (Barker et al., 1998; Bucciarelli, 1994; Cross, 2002; Lawson, 1997; Norman, Cubitt, Urry, & Whittaker, 1995). It is claimed that in order to become skilled problem solvers the students have to construct their own technological-problem-solving mental models. So far, there is a definite lack of research knowledge as regards to the students' mental modeling of technological design processes.

Research questions

The study reported in this paper is part of a larger research aiming to identify the relationship between 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 two alternative approaches to design instruction (structural and functional) and: (1) students' mental models of the technological problem solving process; (2) scope and quality of students' use of various design functions while designing a solution, and (3) the configuration and quality of students' solutions for different problems.

In this paper we report on the results related to the first research question: The relationship between alternative approaches to design instruction (structural and functional) and the students' mental models of the technological problem solving processes.

Method

Population

Participants were 80 seventh graders (junior-high level) attending a comprehensive public school in northern Israel. The students learn design as part of the compulsory science and technology curriculum. They learn in heterogeneous classes in which there are an equal number of boys and girls. The participating students were drawn from four classes, and for this study they were divided into two groups:

(a) Two classes in which the design process was taught by means of the structural approach.
(b) Two classes in which the design process was taught by means of the functional approach.

The participating teacher was selected on the basis of his ample experience acquired during several years' of teaching problem solving in junior high school.

Procedure

The instruction was conducted in the course of 14 meetings, 90 min each.

In both instructional approaches the students had to identify a problematic real-life situation, define the problem in operational terms, and define the requirements and constraints for devising the solution.

The students in the structural-approach group learned the design process stage-by-stage. At each stage they studied the skills and methods required in the solution of their problem. In contrast, the students in the functional-approach group first learned all the design functions (as a manner of tool-kit), for use at each subsequent stage, as the need arose. They were clearly and more than once told that different functions could be used in different stages of the process.

After solving their problem, all students in both groups were given a new problem and asked to design a solution for it.

The study thus was carried out in three stages: (a) pre-test; (b) instruction in two different approaches (structural and functional) focusing on the design of a solution for a student-defined problem; and (c) solution of a new (given) problem.

Data collection and analysis

Data on the students' perception and mental modeling of the design process was collected at six points of the learning process: prior to the learning, three times during the course of learning, at the end of it, and once more about a new problem. The main instrument used for data collection was a *design-process-representation* task. The students were asked to generate a graphic representation of the process required to solve the problem they were working on, as if they had to instruct a peer on how to solve the problem. The representation had to be built as a configuration of different design functions and stages.

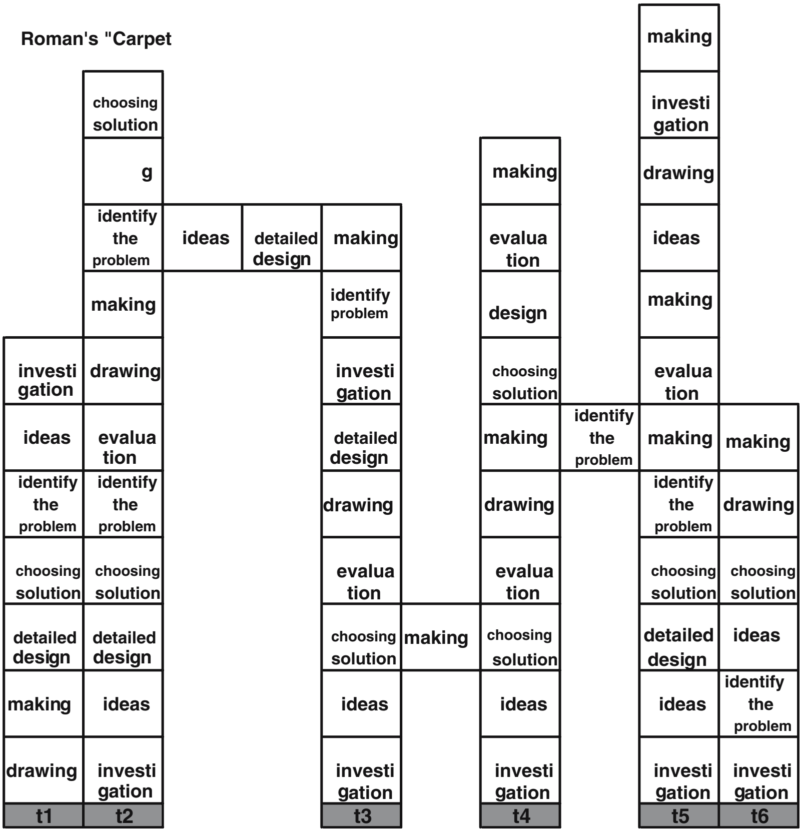

Fig. 1 An example of a student's ''Carpet''

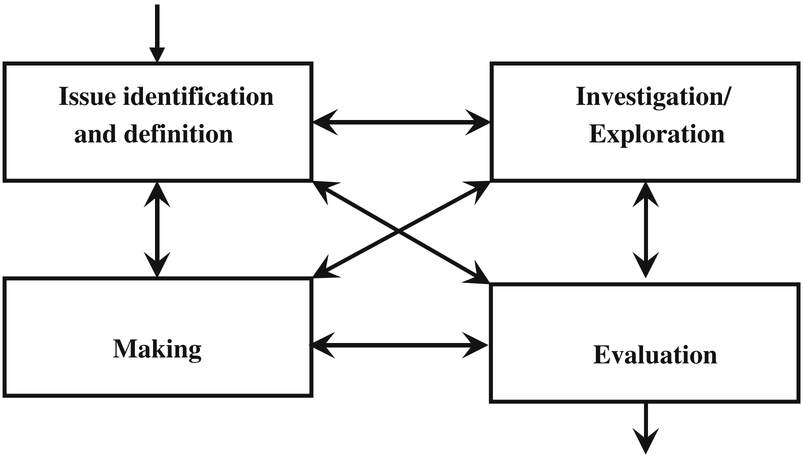

Fig. 2 The recurrent-design-functions framework (Mioduser, 1998)

The collected data were analyzed and organized in a schema we will refer to as *carpets*. Figure 1 presents such a *carpet*, summarizing schematically the student's depiction of the solution-generation process at six different points in time (t1 to t6) during the learning

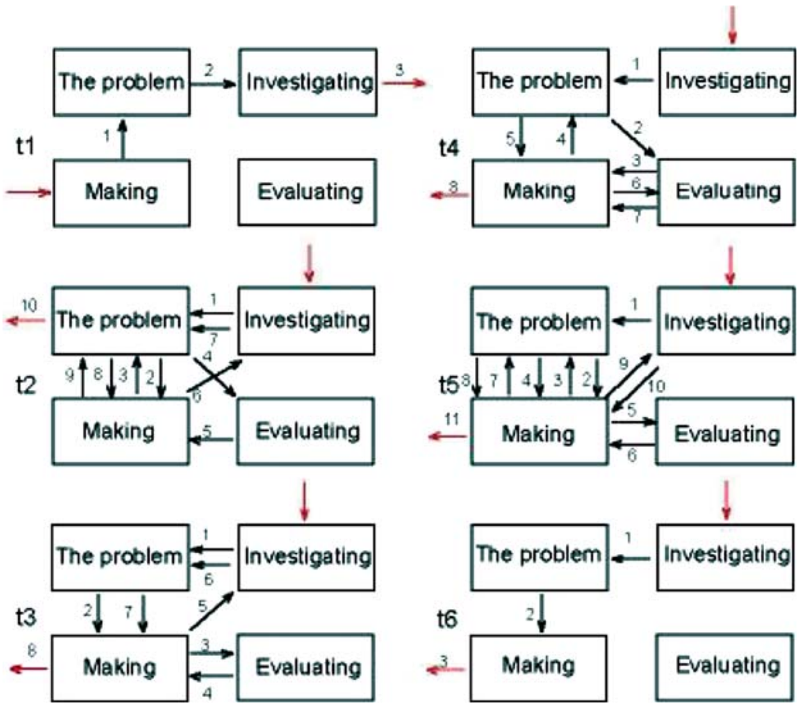

Fig. 3 An example of one student's ''functional models''

process. In the next step of the analysis functional chunks were identified within the *carpets*, defined on the basis of the design-functions framework shown in Fig. 2 (Mioduser, 1998). Each chunk or configuration was aggregated to one of the functions, serving as building blocks to define the students' *functional models* of the design process (Fig. 3). The functional model represents not only the chunks, but also the order and frequency of their occurrence in the students' models. Analyzing each student's set of six models allowed us to construct profiles of development of their mental models of the design process, and to define criteria for comparison among the research groups.

The qualitative analysis was complemented with quantitative procedures to address issues of comparison between groups.

The variables that were the focus of the final stage of the analysis, addressing students' mental models of the design process were: (a) the type of model; (b) changes in the type of model in the course of learning, and (c) defining characteristics and patterns of the students' mental models. A brief description of these variables and their values is presented in Table 1 (a more detailed account appears in the Results section).

Results

Qualitative analysis of the student models

From the students' reports at six points in time (before learning, three times during the learning process, at the end of it, and with a new problem) we constructed, for each student,

Table 1 The variables and their definition and values

The variables	Criteria	Values
Type of mental model	The mental model structure	2- Finite-linear model 3- Cyclical-linear model 4- Branching model 1- Verbal description
Changes in type of mental model during the learning	Focus on the models	Number of students who have changed their models
	Focus on the students	Mean changes in model per student along the learning
Characteristics of the mental model	Use of design functions	The number of functions included in the models
	Recurrent use of design functions in different stages of the solution-generation process	The frequency of recurrent use of design functions
	Use of convergent and divergent functions	1- Many transitions between convergent and divergent functions 3- Moderate number of transitions 5- Clear distinction between convergent and divergent functions
	Complexity of the process depicted	1- Simple 3- Complex 5- Very complex

a profile of the development of her/his mental model of the problem solving process. The criteria for the analysis and its categories emerged from a comprehensive first-order analysis of the students' depictions of the design process.

Below is a summary of our qualitative observations in relation to the types and characteristics of the models students constructed. Four types of models were identified (see Fig. 4):

- *Finite-linear model*: The students described the problem solving process as a series of stages/functions ordered in a linear manner.
- *Cyclic model*: The students described the problem solving process as a series of stages/functions including return paths to previous stages/functions.
- *Branching model*: The students described the problem solving process as a solution space with branching nodes.

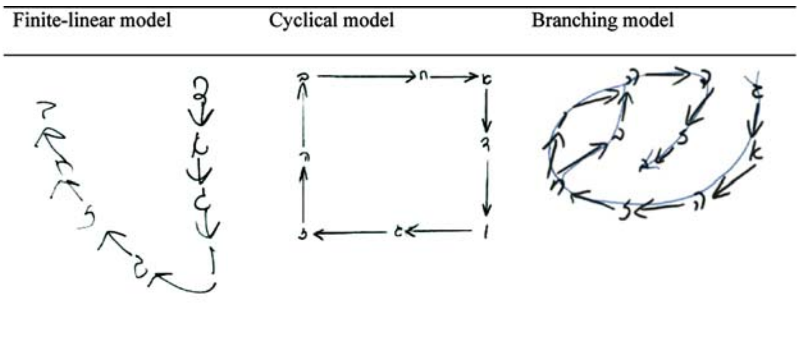

Fig. 4 Types of models generated by the students

In addition, some students described the problem solving process only *verbally*, without any graphical representation of it. In this case, the students used the words supplied in class for naming eight design functions.

Characteristics of the students' mental models

The qualitative analysis of the student models focused on three main aspects related to the inclusion and use of the various design functions and the configuration of the depicted models (it should be noted that in this section we survey, for each aspect analyzed, all different appearances regardless of frequencies or quantitative predominance—the latter will be presented in the next section).

The first aspect analyzed referred to the *type and number of design functions* included in the models. In the simplest configurations the students included the eight design functions supplied in the 'instructional toolbox' just, and in some cases even not all of them. Several students used some specific functions more than once. Some of them were consistent in the use of specific functions along the process (t1–t6), while others used different configurations each time. For example R. used only four functions at t1 and t6 (at the beginning and end of the process), and at t2–t5 he included the functions *making* and *investigating* three times. Overall, R. included 13–14 functions in each of his depictions of the design process.

The second aspect analyzed focused on the inclusion of *divergent* and *convergent* functions in the models. *Divergent* functions are the ones by which different options and alternatives are opened, expanding the space within which the design process proceeds. Functions related to the generation of alternative solutions, or to searching for new information, pertain to this category. *Convergent* functions are those that require that the student make choices, and decisions, and concentrate on a specific goal. Functions such as selection of the optimal solution (according to criteria) or planning its implementation pertain to this group: we looked after the *separate* or *simultaneous* use of these types of functions, and on *transitions* between these. From the students' *carpets* analysis, three modes of organizing convergent and divergent functions were found: many transitions between convergent and divergent functions, few transitions, and separate use of functions, i.e., first divergent functions (e.g., *generating ideas*) and afterwards convergent functions (e.g., *choosing a solution*). The frequency of these different configurations within and among groups is discussed in the next (quantitative data) section.

The third aspect in the analysis referred to the *complexity of the design process* depicted. The set of models observed ranged from very simple linear models to complex branching models with many transitions among four main functions (*issue identification*, *investigation*, *making*, and *evaluation*). For example, in Fig. 3 the analysis of one student's depictions of the design process in the course of learning is presented. At stages t1 and t6 the student's model is of low level of complexity, with only a few transitions among functions. These were in fact stages at which the student faced a new problem—the problem to be solved during the learning process at t1, and the new post-test problem at t6. In contrast, during the learning (the design process of the solution for the problem), from stage t2 to t5, the student models of the design process became far more complex, with many transitions among design functions appearing in recurrent manner according to the typical requirements of each stage (e.g., retrieval of information on alternative materials, evaluation of candidate solutions and decision making). An example of the dense cyclical character of the process can be seen in the model at t5, in which the student went back and forth between the definition of the problem and the making of the solution, resulting in fact in the progressive revision and refinement of requirements and constraints, and in the construction of successive versions of the solution until its completion.

The *recurrent use of functions* was in fact a defining characteristic of the more complex student models, and we will refer to it quantitatively in the next section.

Quantitative analysis of the student models

Following the qualitative analysis stage in which the main characteristics and properties of the student models and their change patterns along the learning process were identified, we conducted additional quantitative analyses of the data. The focus in this stage was on the relative weight of the different qualitative findings in the whole learning process, and on the comparison between groups as regards to the identified issues.

Types of student models of the design process

The frequencies of the different types of models of design as they occurred in the students' drawings are presented in Table 2. Since only few students in both groups generated representations of the branching type, these were excluded from the quantitative analyses.

In the structural-approach group (S-group) half of the students represented the design process by finite linear models, and the other half by the cyclic model. This distribution among types of model was similar and consistent in most stages along the learning. An exception was t5, in which the majority of the students (61%) opted for the linear model, one third for the cyclical model, and about 7% did only a verbal description. It should be noted that t5 represents the end of the learning process, therefore the end the design project. It seems that the students' representation of the design process summarizes their understanding of its configuration after completing their learning in the structural (stage-by-stage) approach. Hence, the final model of the process was envisioned by most of the students as a linear one.

In the functional-approach group (F group) most of the students represented the design process, in most stages, by finite linear models, and just about 10–30% by cyclic models. In two stages, t1 and t5, a considerable number of students (28%) generated only verbal descriptions of the design process. These findings appear to contradict what we [might have] expected for the F group: given that their learning neither followed any structured plan, nor did they learn the design process as a stage-by-stage process, it would have been reasonable to expect more cyclical and branching models among their representations. A possible explanation for these findings emerges when we consider them together with additional characteristics of the F group student models, e.g., the recurrent use of design functions. In fact, these linear models include many repetitions of the same function or

Table 2 Distribution of type of mental models for both groups (percentage of students)

Group	Time Model	$t1^{**}$ (%)	t2 (%)	$t3^{*}$ (%)	$t4^{**}$ (%)	$t5^{*}$ (%)	$t6^{**}$ (%)
Structural	Linear	50	48.1	51.9	53.3	62.1	43.5
	Cyclical	46.9	51/9	48.1	46.7	31	56.5
	Verbal	3.1				6.9	
Functional	Linear model	59.4	68.8	81.5	88	60.7	89.3
	Cyclical	12.5	31.3	18.5	12	10.7	
	Verbal	28.1				28.6	

$^{*}p < 0.05$; $^{**}p < 0.01$.

recurrent use of a function in different contexts. This implies in fact the existence of cycles and branching points, which, when represented in chronological terms, resulted in a sort of ''flattened'' version of a complex model. In other words, these models are linear in form but not in content. We will elaborate more on this issue in the discussion section.

Consistency in type of model along the learning process

The extent of consistency in the students' model of the design process along the learning was measured by two variables: the number of students who changed type of model along the learning process (from t1 to t6), and the average number of changes made by each individual student along this process.

In the S group about half of the students did change their model in the course of learning (53.4%). In the F group the representations of the design process generated by the vast majority of the students (83.3%) showed transitions among models. A more detailed account of the number of changes in model made by each individual student in both groups, shows that the mean number of changes in the F group (1.833) was higher than that in the S group (1.086) at a significant level ($t = -2.39$; $p < 0.05$).

Overall these differences reflect the students' perception of the design process in correspondence with the instructional approach implemented. Sgroup students were exposed to a structured and organized process, in which every new stage was added in tandem with the previous ones. The results are fairly stable models in which development (along successive stages) implies expansion rather than modification or change. In contrast, F-group students had to face the need to plan and make decisions as regards to the character of the next step and to the function to be implemented at every stage. These students had to revise and reconstruct at every decision point their perception and perspective of the process, and envisage its continuation in advance. The result was the dynamic character of these models, something that was well reflected in the quantity and quality of changes made by the students along the learning process.

Characteristics of the students' mental models

The quantitative analysis of the student models as regards to their properties or characteristics was performed for four variables: (a) the number of design functions included in the representations; (b) the extent of recurrent use of design functions in different stages of the solution generation process; (c) the use of functions defined as either convergent or divergent (more on their definition appears later); and (d) the complexity of the model (Table 3) .

Table 3 Comparison between groups of mental model characteristics Variables

	S group (Mean)	F group (Mean)	Mean difference between groups	t value
Use of design functions	0.61	0.65	−0.04	-2.29^{*}
Recurrent use of design functions	0.229	1.31	−1.077	-2.63^{**}
Use of convergent and divergent functions (scale: 1–5)	3.29	2.17	1.12	1.99^{**}
Complexity of the process depicted (scale: 1–5)	2.52	2.89	−0.37	-2.14^{*}

* $p < 0.05$; ** $p < 0.01$.

Concerning the number of functions included in the representations, every student was graded for the number of functions she/he used in all 6 representations (t1–t6) of the design process, out of the maximum possible—72 appearances of the functions (9 different functions in 6 probing times). We found that the mean in number of functions used in the F group was higher than that of the S group (0.65 and 0.61 in correspondence), at the significant level ($t = -2.29$ $p < 0.05$).

A key quantitative indicator of the students' ability to choose and use the different design functions according to needs and contextual requirements is the recurrent use of the different functions. For this variable we looked at various aspects such as the number of design functions recurrently used; the most frequently included functions, or their location in the depicted process. In both groups the recurrent use of the functions *investigation, planning, drawing* and *choosing a solution* was of similar frequency. However in addition, F group students also made recurrent use of the functions *evaluation, making* and *generating ideas*, in fact the complete repertoire of functions in the ''design-functions-toolbox''.

The mean score for the recurrent use of design functions per student was higher in the F group (1.31) than in the S group (0.229), at the significant level ($t = -2.63$, $p < 0.01$). F group students used the various design functions in flexible and complex ways in their representations, expanding and adapting their model as they proceeded in the different phases of the planning and making of the technological solution.

For further analysis of the quantity and quality of use of the different design functions while representing their models, these were grouped into divergent and convergent functions. Divergent functions open different options and alternatives, expanding the space within which the design process proceeds. Functions related to the generation of alternative solutions, or to the search for new information pertain to this category. Convergent functions are those that require the student make choices and decisions and concentrate on a specific goal. Functions such as selection of optimal solution (according to criteria) or planning its implementation pertain to this group. All *carpets* generated out of the students' representations were analyzed to identify transitions between convergent and divergent functions. The models were characterized as to whether they showed transitions among types of functions, or comprised mainly one type of function. In the grading scale we have built, the inclusion of transitions was graded higher than the use of only one type of functions. Overall, we found that F-group student models included numerous transitions among types of functions all along the learning. In contrast, Sgroup student models included in the early stages mainly divergent functions, and in the later stages mainly convergent functions. In correspondence, the mean score for F-group students was higher than that of the Sgroup students, at the significant level ($t = 1.99$, $p < 0.01$).

In a different grouping, we aggregated all design functions into four main categories, corresponding to those suggested in the functional model for design instruction (Mioduser, 1998): *issue identification*, *investigation*, *making* and *evaluation*. The complexity of students' models of the design process was defined by the number of transitions between the above four main functions. In a scale of 1 (few transitions) to 5 (numerous transitions), the mean score of the F group (2.89) was higher than that of the S group (2.52) at the significant level ($t = -2.14$, $p < 0.05$). As shown in the example depicted in Fig. 3, student models in the F group reflected far more complexity in their approach for solving the technological problem (comprising numerous transitions and cycles among all design functions) than the S group students' approach.

Discussion

In many countries all over the world, design skills and concepts are key components of the technology curriculum for all age levels (e.g., as reported by the USA International Technology Education Association, 2000, or in the Israeli curriculum in Science and Technology Education, 1996). The model of design included in most curricula is based on its perception as a systematic step-by-step process. On this approach, the main goal is for the students to be able to apply this systematic model for solving problems in future situations both in class and the real world. However, a considerable amount of research done so far stresses serious drawbacks in this instructional approach, due to students' difficulties in developing a holistic perception of the design process of technological solutions, and in acquiring transferable design skills (Chidgey, 1994; Hennessy & Mccormick, 1994; Hill, 1998; Hill & Anning, 2001; Johnsey, 1995; Kimbell, 1997;). Neither expert problem solvers nor students follow strict and predetermined courses of action in their design work. It is surprising that in spite of these findings, curriculum developers and teachers all over the world still rely almost exclusively on the structural approach to teach technological problem solving (Hutchinson & Karsnitz, 1994; Mawson, 2003; Todd, 1990, Waetjen, 1989).

In light of the above findings, we suggest the implementation of a different instructional approach focusing on design functions, or a conceptual design tool kit, rather than on design stages (Hennessy & McCormick, 1994; Johnsey, 1995; Mawson, 2003; Mioduser, 1998; Hill, 1998). By this approach, the design process -from the problem identification phase to the completion of a working solution—is built as a flexible, cyclical and adaptive configuration of design functions and intellectual design tools. The purpose of the study we report on in this paper was to examine the effect of the instruction in the alternative approach—the functional approach—on the students' perception and mental modeling of the technological problem solving process.

In the beginning of the study we found that the students held intuitive mental models of design based mainly on their experience in performing daily-life problem solving. These intuitive models revealed a lack of systematic and relevant design knowledge. During the learning process and at the end of it, significant difference was observed between the students' mental models in both groups and in all sets of variables examined (i.e., type of model, changes in type of model along the learning/design process, and characteristics of the model). We found that students in the F group developed mental models that resembled those of expert designers in characteristics such as flexibility, change in the course of the process, and recurrent use of design functions (Bucciarelli, 1994; Cross, 2002; Lawson, 1997). The significant and continuous changes in the F group's models in the course of the learning process are indicative of their ability to reconstruct and adapt the models in light of incoming data (Norman, 1998). These features were far less frequent among the Sgroup students.

An intriguing finding is that it was F group students who generated mostly finite-linear representations of the design process. Our interpretation of this finding relates to the nature of the working process these students underwent: lacking a predetermined structural skeleton, they had to make decisions about the next step or activity at every stage of the problem solving. Often the next step required the re-activation of a design function already instantiated in previous stages, this time adapted to the new context and requirements. As a result, their account of the process reflected all decision points in time (or in chronological—linear—order). However, these linear descriptions included many repetitions and cycles, so that in fact they can be seen as ''flattened'' representations of complex cyclical models.

Investigation and *exploration* were among the most frequent recurrent functions used by students in the F group. This clearly indicates that these students became aware of the importance of information gathering and analysis in the various stages of the design process. For example, the *exploration* function was instantiated to meet different goals and contents along the process: for identifying the issue or problem to be solved; for defining requirements and constraints for the solution; for reviewing previous solutions for similar problems; or for comparing candidate materials or procedures. In contrast, the scarce use of the *investigation* and *exploration* functions by the S-group students is indicative of their perception of information gathering as a specific and local stage in the process (i.e., search for alternative solutions). In most other stages, an almost exclusive use of intuitive knowledge was observed among these students (Jones, 1997; Kimbell, 1997; McCormick, 1997; Oliver & Hannafin, 2001).

From the instructional perspective, we can elaborate on the effect of the defining features of each instructional approach on the student models of the process. In the functional approach, the teachers supplied conceptual tools (the functional tool-kit) and the overall goals and guidelines of a process expected to evolve dynamically. In each and every lesson the students had to develop their own image or scenario of the particular stage, which obliged them to revise and reconstruct their model of the process (Hasslbring, 1994). This required that they move mentally between the systemic level (their perception of the process as a whole) and the specific level (the particular design activity at any given stage), much like the experts' modeling of the design process (DeKleer & Brown, 1981; Hegarty, 1991; Kieras, 1988; Norman, 1983; White & Frederiksen, 1986). In contrast, in the structural approach, the students were taught the ''right'' and stage-wise model to follow, while ignoring any alternative processes they possibly might have held (Chidgey, 1994; Hennessy & McCormick, 1994). As a result, S-group students constructed to a large extent partial, localized, and inflexible mental models.

Overall, we might conclude that the functional approach towards design instruction was more effective than the traditional structural approach for supporting the construction of holistic, flexible, and effective mental models of the design process of technological solutions. By demanding from the students to actively revise their models at each and every stage and make decisions about the next step to be taken, learning becomes a highly constructivist process. We believe the need to explore this claim even further is great, following the findings of our study—larger populations at different age levels and different technology education settings would have to be addressed.

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