STUDENTS' CONSTRUCTION OF STRUCTURED KNOWLEDGE REPRESENTATIONS

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Abstract

Students, while acquiring as well as communicating knowledge, are regularly engaged in processes related to the organization and representation of information. However, representational skills and processes are not explicitly taught, and the process by which students learn and apply these skills is an issue still in need of systematic study. This paper describes an exploratory study on the acquisition and use of knowledge representation skills and structures by sixth graders, supported by a computer-based learning environment. The results indicate that these symbolic structures can be successfully taught, and that students using them in the context of instructional tasks perform at the higher band of cognitive processes; that constructing computer knowledge bases affected the students' abilities to analyze, organize and represent knowledge; that the students were able to create representations of considerable structural complexity and varied nature (e.g., "taxonomic", "encyclopedic", and "classification" trees) and content. As a corollary a series of issues which deserve a deeper and systematic inquiry are presented (e.g., the repertoire of symbol structures or schemas which are better candidates for teaching should be defined; the learning and application process of these intellectual tools should be traced; and the refinement process of these schemas once acquired and repeatedly used should be studied, along with their "cognitive robustness").

STUDENTS' CONSTRUCTION OF STRUCTURED KNOWLEDGE REPRESENTATIONS

Students, while acquiring as well as communicating knowledge, are regularly engaged in processes related to the organization and representation of information. Almost all tasks students face during their schooling require using some kind of organizational structure (e.g., charts, tables, text-composition templates) while manipulating information items from varied sources (e.g., textbooks, newspapers, teachers, the student's own knowledge-base), for that information to be used in solving problems, answering exam items, preparing surveys and reports, or delivering presentations. Moreover, it has been suggested that "in formal thinking, the structure is the message" (Ohlsson, 1993, p. 62), and that approaching unfamiliar knowledge or generating new knowledge are propitiated by the use of the kind of symbol structures referred to in the literature as representational structures (Mioduser, 1990), thought-forms (Keegan, 1989), epistemic forms (Collins & Ferguson, 1993) or abstract schemas (Ohlsson, 1993).

However, at least in two main aspects these theoretical formulations have yet to find their way into the educational practice. First, representational skills and processes are not explicitly taught, following the assumption that somehow they will develop as a by-product of schooling. Second, the process by which students learn and apply these skills is an issue still in need of systematic study (Mioduser, 1990; Ohlsson, 1993).

This paper describes an exploratory study on the acquisition and use of knowledge representation skills by sixth graders, supported by a computer-based learning environment called "The Knowledgeable Tree" or "K-Tree". In the coming sections we present a review of related research, a description of the learning environment and its rationale, and the study design, results and conclusions.

Background

This study relates to the role of technology, more precisely of knowledge representation formalisms, mediating between knowledge and human cognition. Previous relevant work can be referred to at two main levels: theoretical considerations and teaching and learning studies.

Theoretical considerations

The theoretical perspective can be introduced in the form of an interesting loop: human cognition invented artificial constructs, which in turn have the potential of empowering human cognition if internalized by it (Mioduser, 1990; Salomon, 1988). The history of the development of powerful artificial knowledge manipulation constructs is as ancient as human culture itself (Hauser, 1951; Olson, 1976). In the past these inventions took the form of formal symbol systems and notations (e.g., the alphabet), formal reasoning devices (e.g., Logic), or physical tools (e.g., calculation devices). Nowadays this repertoire is growing at extraordinary pace sustained by the constant and rapid development of microprocessor-based technologies. Relevant for this study are representational structures and methods developed within the artificial intelligence and cognitive science fields, e.g., semantic networks (Quillian, 1967), frame systems (Minsky, 1975), or case-based reasoning (Riesbeck & Schank, 1989), and computer tools embodying these constructs, e.g., EESS (Scherz et al., 1988), “Knowland” (Mioduser, 1989), or SemNet (Fairchild, Poltrock & Furnas, 1986).

A central theoretical claim to be considered was defined by Salomon (1988) as “AI (Artificial Intelligence) in reverse”, or the process by which students internalize cognitive constructs while interacting with (computerized) knowledge-manipulation tools. Two issues concerning the internalization process are of relevance for our study. The first is that it is not merely a copying process of functions or features of the external tool, but a cognitive reconstruction process by which a set of operations, procedures and methods are assimilated thus enriching the student’s cognitive apparatus with new structures. The second issue is that this internal reconstruction requires the student’s active participation in, and control of the learning process with the tool. Mere exposure to it’s features (even if it is a highly “intelligent” and sophisticated tool) does not suffice for internalization to take place.

Internal knowledge-manipulation constructs are referred to in the literature as representational structures (Mioduser, 1990), thought-forms (Keegan, 1989), epistemic forms (Collins & Ferguson, 1993) or abstract schemas (Ohlsson, 1993). Let us expand a bit on the last two.

Abstract schemas encode form (rather than content), and serve as tools for formal thinking (understood as formal processes that operate on symbol structures). They are refined from actual experience, becoming cognitive tools for facilitating both understanding and production of symbolic entities. Ohlsson suggests a taxonomy of abstract schemas, including descriptive schemas (e.g., hierarchical classification, trees, networks), explanatory schemas (e.g., Darwinian explanation, feedback cycles, means-ends analysis), compositional schemas (e.g., atomic theory of matter, Chomskian syntax), or quantitative schemas (e.g., correlation, distribution). It is suggested that, fostering high-end cognition, such general-purpose and powerful constructs are suitable targets for instruction.

In a similar venue structures and strategies guiding scientific inquiry were referred to as “epistemic forms” and “epistemic games” (Collins & Ferguson, 1993). These forms and structures are epistemic in the sense that they relate to the construction of new knowledge. School instruction consists mostly of facts, concepts, fixed methods and given models. It is widely agreed that students should also learn general-purpose and flexible cognitive skills to guide their inquiries and production of new knowledge, such as the epistemic forms. These structures can be of varied kinds: structural (e.g., tree or hierarchical structures, stage models, primitive-elements decomposition), functional (critical-event, cause-and-effect, or form-and-function analyses), process analyses (system-dynamics models, aggregate-behavior models, cyclical analysis). Being these tools so powerful,

> “...it would make sense to teach them to students along with the facts, concepts, methods and theories we now teach. Like any complex game, however, they cannot be learned in rote fashion. They can only be learned from trying to make sense of different phenomena” (Collins & Ferguson, 1993, pp. 40)

The briefly reviewed theoretical considerations lead to a twofold preliminary conclusion: (a) knowledge-manipulation structures and skills are appropriate candidates for instruction if our aim is to support high-end cognition, and (b) the learning and implementation processes of these structures by students has yet to be comprehensively studied (e.g., by age levels, content areas, individual differences, task complexity).

Teaching and learning studies

Review of the literature on the educational implementation of knowledge-manipulation tools shows that interesting and varied work has been done. Reported work focuses on the use of graphical representations (e.g., Kindfield, 1994), formal representational structures (e.g. frames, productions, semantic networks; Mioduser, 1990; Fisher, 1990), concept and vee mapping (e.g. Novak, 1990), or state diagrams and flowcharts (Levin & Mioduser, in press).

A revealing observation is that for several years (and at some extent still today) the use of these tools mainly by teachers and developers for instructional planning, development, and assessment was the major application trend (e.g., Starr & Krajcik, 1990). For example, concept mapping was at first the researcher's modeling tool of the knowledge-state of the studies subjects. But gradually the cognitive value of the representational tools became evident, and their role in learning turned to be a fertile subject of study (Novak, Gowin & Johansen, 1983).

A comprehensive review of research findings is beyond the scope of this paper, but we will briefly refer to a few relevant findings and conclusions.

Studies were conducted at varied age levels, e.g., primary level children (Symington & Novak, 1982), junior high students (Novak, Gowin & Johansen, 1983; Mioduser, 1990), or college students (Heinze-Fry & Novak, 1990; Kindfield, 1994). In general terms, these studies showed that: (a) students can learn the representational tools, although the question of how long it takes for the students to mastery the skills until they become robust intellectual tools still deserves answers;

(b) Differences between “representers” vs. control groups were not, in most cases, statistically significant. But the results invariably showed better performance for most variables (e.g., learning, retention, organization imposed on the topic) for the experimental groups; (c) Unequivocal evidence of correlation between ability level and representation performance was not found. Some studies report that gains were observed at all ability levels, while others stated that high-ability students benefited most from the learning experience. Low-level students’ representations tended to be more literal and less generic, overloaded with visual and obvious details, less generalizable; (d) Students claimed that representational experience affected their learning (e.g., increasing integration of knowledge, organization, understanding); (e) The constructed representations contributed to reduce the cognitive load of instructional tasks (e.g., by functioning as external storage devices, or facilitating the visual identification of organizational templates or knowledge chunks); (f) Representational tools appear to be suitable for all subject matter.

From previous work we can learn that the potential is there - knowledge representation formalisms are convincing tools for supporting meaningful learning and high-end cognition. But research is far from being conclusive regarding a whole range of issues, e.g., integration in regular schooling (as opposed to lab-like pilot implementation), nature and quality of representational process at different age levels, developmental perspective of formal representational ability, fine-grained characterizations of representations generated by students. Moreover, only a minor part of previously reported work involved the use of technology other than paper and pencil. This is somehow a paradox considering that most formal constructs we are referring to were developed for computational purposes, or within the framework of computational modeling of cognition. The study reported here deals with some of the above mentioned questions while students work with a computerized tool for constructing structured representations of knowledge.

The “K-Tree” Learning Environment

The “K-Tree” learning environment is basically a computer shell written in the Logo language, which enables students to create tree-like representations of knowledge. The tree may contain textual as well as visual information, organized hierarchically according to criteria defined by the student. Once introduced into the computer, the tree serves as a knowledge-base which can be consulted by its author or other students by means of a friendly search mode. The general configuration of the representational structure allowed by the shell is shown in Figure 1.

Insert Figure 1 about here

The development of the learning environment followed the essentials of two conceptual approaches. The first is the “Student-as-Epistemologist” approach (Harel & Papert, ; Papert, 1980). In our project, the student is involved in transforming a loosely defined body of knowledge into a runnable representational system. The creation of a structured representation of knowledge (e.g., a tree-like representation in our project) requires the identification and definition of discrete units of information (the nodes in the tree), and the structural and functional interrelations among them (Brachman & Levesque, 1985). We believe that being involved in such a cognitively demanding process may significantly affect both learning and knowing.

Our second theoretical source is the "Cognitive Technologies" approach (Olson, 1976; Pea, 1985; Salomon, Perkins, & Globerson, 1991). Here a central trigger for cognitive apparatus development are the demands and opportunities afforded by the knowledge technologies with which the student interacts. A central idea in our project is that the representational process and skills embodied in tools like the “K-Tree” may be assimilated by the students as “cognitive artifacts” for coping with knowledge organization and manipulation (Mioduser, 1990; Wideman & Owston, 1993).

The “K-Tree” learning environment consists of the computer software and two student booklets. The sequence for working on the set of representational concepts and skills is shown in Figure 2.

Insert Figure 2 about here

The Study

The study reported here was aimed at tracing the process by which students acquire representational skills and apply them in building computer knowledge bases. In general terms we focused on three main research questions:

1. Can representational skills and structures be taught?

2. How does the involvement in constructing computer knowledge bases affect the student's ability to analyze, organize, and structurally represent knowledge?
3. What is the quality (regarding relevant features such as complexity, depth, branching, or volume of information) of the knowledge bases that the students are able to create ?

Method

Two regular 6th grade classes participated in this study, one functioning as the experimental group (n=35), and the other as the comparison group (N=41). Both classes were in public schools covering grades 1 to 6, located in working-class neighborhoods near San Jose, Costa Rica's capital. These schools were participating in a nationwide educational computing project carried out by the Omar Dengo Foundation. The students' previous experience with computers consisted mainly of basic programming with the Logo language.

Procedure. The experimental group worked on a series of activities that focused on the building of tree-like representational structures, while the comparison group continued for the same period with their regular computing classes. The learning activities were taught to the experimental group in part by the authors and in part by the classroom teacher, following the sequence shown in Figure 2. The class met for twelve sessions over a six-week period. Most sessions lasted 90 minutes. The activities were taught within the time slot, and as part of both science studies and computer studies. The first four sessions (focusing on basic concepts and skills related to classification, category formation, tree-like representations) took place in the regular classroom. The students were first involved in doing classifications and categorizations of familiar objects (e.g., pens, books, coins). They were requested to justify their criteria for defining categories and groups. The next series of tasks focused on defining relationships among groups of objects, e.g., hierarchy, class inclusion, properties of different levels of generality or specificity, inheritance paths. The final task for this stage was the building of the first representational tree for the objects considered. The remaining classes dealing with the gradual construction of exemplar and student-designed trees were conducted in the computer lab. The exemplar tree all students built and entered into the computer was about Dinosaurs. Once the basic tree was defined the students used it to classify two new instances of Dinosaurs, actually two invented creatures created by combining parts from different animals. Next the students were asked to create their own trees on a science topic. The task's objectives were defined as: (a) creation of a computer expert containing a structured (tree-like) representation of knowledge about a chosen topic, and (b) the tree should serve other groups as knowledge source for performing an academic task on the chosen topic. The challenge now was to perform the whole process (e.g., analysis, definition of knowledge units, definition of relationships and hierarchical structure, computer work) on a completely new topic of their choice. In addition, unlike the previous trees for which only nodes and links were defined, the students had to expand part of the nodes with textual and visual information for the tree to serve as a reasonable knowledge base. The sequence was closed with a recapitulation and discussion class. Part of the exercises, information gathering, and design work was done by the students as homework. The planning of the representation tree and the computer work was done in small groups of two to three students per group.

Data collection. Data were collected as follows.

1. A pre and post-assessment was administered to both groups (to the experimental group during the first and last sessions of the instructional sequence). The-assessment consisted of two open questions: (a) Describe in some organized way the various items in your kitchen at home, and (b) Can you describe visually and in an organized way the various items in your kitchen at home (e.g., diagram, graph, illustration)? Draw this representation in the space below.
2. Data about students' representations were collected from two sources: the design worksheets, and the students' computer files. A total of 13 computerized representations were planned and created by a similar number of groups.
3. Six teachers were asked to assess students' representations, applying their usual evaluation criteria.
4. Observational data were collected at different stages of the students' work.

Results

The results will be presented in the next two sections in correspondence with the research questions. The first section presents the pre and post-assessment results addressing the second research question, namely, how does the involvement in constructing computer knowledge bases affect the student's ability to analyze, organize, and structurally represent knowledge. The second section analyzes the student designed knowledge bases addressing the third research question, namely, assessment of the quality (regarding relevant features such as complexity, depth, branching, or volume of information) of the knowledge bases that the students were able to create. The first research question regarding the teaching of representational skills and structures will be addressed, following the results, in the discussion section of the paper.

Pre and Post-assessment results

As already mentioned the pre and post-assessment consisted of two open questions: a description of the various items in the student's kitchen at home, and a visual representation of these items. Focusing on the research question regarding if and how the learning process affected the students' ability to analyze organize and structurally represent knowledge, four features of their responses to the assessment questions were analyzed: number of items mentioned in the description, mention of organizational criteria, organizational template (implied in the written description), and representational template (implied in the visual description). The following is a description of the analyzed features (Tables 1 to 4), and of the comparison between the performances of the experimental and control groups (Table 5).

We first considered the number of items mentioned in students' written descriptions. Table 1 shows almost no differences between the pre- and post-assessment in number of items mentioned, neither in the experimental nor in the control group (18-19 items for the experimental group and 10-11 items for the control group). Most students mentioned between 10 and 20 items in their descriptions. This result may suggest that the way the learning process affected the nature of the students' representations, if at all, should be reflected in the qualitative rather than the quantitative features of the representations.

Insert Table 1 about here

The second feature we analyzed was the mention of any organizational criterion (e.g., size, function, material) for the description of the kitchen and its contents. We did not consider spatial aspects (e.g., location, orientation) as valid criteria . When spatial features were mentioned they served, in most cases, as an aid in portraying the kitchen (as in a "guided tour") rather than as an organizational or conceptual criterion for building the description.

Insert Table 2 about here

Most students did not mention any organizational criterion at the pre-assessment (80% in the experimental group; 98% in the control group). For the control group the figures remained the same at the post-assessment. For the experimental group the number of students who used some organizational criterion in their verbal description increased from 20% in the pre-assessment to 40% in the post-assessment. The difference for this aspect of the student descriptions between the pre and post-assessment was significant for the experimental group ($t(34)=2.22$; $p<0.05$), but not for the control group.

The third and fourth features of the representations we analyzed referred to the nature of the representational template implied in the written and visual descriptions generated by the students.

The written descriptions were classed using a five-level scale of organizational templates (see appendix A for examples of student descriptions for each level):

(1) Enumerative, where varied items (e.g., appliances, objects, food items) appear arbitrarily listed.

(2) Spatial, with location in the kitchen's space being the main feature guiding the description (e.g., in the form of a "guided tour").

(3) Functional, where items are grouped and described according to their functions (e.g., for cooking, for storing food)

(4) Semi-structured, where some sort of representational formalism appears side by side with any of the previous templates (e.g., definition of groups, links between these groups).

(5) Structured, where formal-representation approach clearly guides the description (e.g., categories formation, hierarchy, class inclusion).

Insert Table 3 about here

Table 3 shows the frequency distribution of the students' descriptions over these five categories. At the pre-assessment most students in the experimental group generated descriptions of the enumerative type (69%), and in the control group of the spatial type (67%). Only a few descriptions in both groups did belong to the higher categories. At the post-assessment the table shows interesting differences in the distribution of the experimental group descriptions. At the lower end of the scale the number of merely enumerative descriptions decreased to about 37% of the responses. And at the higher end the same proportion of students (37%) generated semi-structured or structured representations (only 8% at the pre-assessment). In the control group the distribution remained similar to that of the pre-assessment.

The visual representations were classed using a three-level scale of representational templates (see appendix A for examples of student representations for each level):

(1) Realistic illustration. This is a literal representation, showing the kitchen and its contents by a sort of photographic approach.

(2) Conceptual illustration. The representational means are still realistic, but the representation is no longer literal. Its parts refer to categories and make use of conceptual representational-resources (e.g., "x-rays", generic forms or object representations, conventional symbols).

(3) Formal representation. The visual representation is graphical or diagrammatic, including the use of formal structures and notations (e.g., tables, trees, block diagrams).

Insert Table 4 about here

Table 4 shows the frequency distribution of the templates of the students' visual representations. Most representations in the pre-assessment were realistic illustrations of the kitchen space and objects. No formal representations were created at this stage. At the post-assessment 23% of the experimental-group students did create formal representations, while the distribution for the control group remained the same as in the pre-assessment. About the same number of students in each group (around 10%) produced a conceptual illustration in both the pre and post-assessment.

The written and visual representations were used in this study for comparing the performances of the experimental and control groups. Table 5 summarizes the results of the comparison.

Insert Table 5 about here

No significant differences were found between the groups at the pre-assessment stage, neither for the organizational template of the written descriptions nor for the representational template of the visual representations. In contrast, significant differences were found between the groups in both aspects at the post-assessment stage.

In addition, no significant differences were found in the control group between the pre and post-assessment, while significant differences appeared in the experimental group between these stages for both the organizational and the representational templates.

Appendix B shows one student’s pre and post, written and visual representations exemplifying these differences. For the written representation the example shows the transition from a concise and arbitrary list of objects (enumerative description) towards a criteria-based and systematic description (structured description). The first part of the description is based on the criterion of size (e.g., big objects, mid-size, small). The second part expands on some salient sub-groups as defined by some particular property (e.g., cutting tools, decorative objects).

For the visual representation the example clearly shows the change from a pictorial or realistic representation to a formal tree-like representation. This example is representative of the performance of about a third of the students' in the experimental group.

The Student-Designed Knowledge Bases

The section of the results addresses the third research question namely, the assessment of the quality (regarding relevant features such as complexity, depth, branching, or volume of information) of the knowledge bases that the students were able to create.

The students' main task was to generate a tree-like knowledge-base on a curricular topic. Their work proceeded according to the following stages: (a) Choice of the topic, (b) Location of information sources and information gathering, (c) Analysis of the information and definition of representational units or nodes in the tree. These definitions included decisions about structural and logical relationships among the units (e.g., degree of generality, hierarchy, class inclusion), (d) Definition of the information to be attached to each node (e.g., definitions, descriptions, explanations, examples), (e) Actual building of the computerized tree using the Logo environment.

Thirteen trees were created by the students working in pairs or threesomes. Our analysis and evaluation of the trees focused on three issues: Topic, nature, and structural complexity. In addition, we asked six teachers to evaluate the students' trees using their own evaluation criteria.

Topic

The topics chosen by the students were from the various disciplines of the natural and social sciences curriculum: Geological and geographical aspects of Costa Rica (four trees), classification of the natural world (two trees), anthropological aspects of pre-Colombian cultures (two trees), the flower and its parts, the human skeleton, minerals, and birds (one tree each). One group preferred to develop on the topic they met in the pre-assessment, namely, the kitchen components and objects, and not on a curricular topic.

Nature

Analysis of the trees showed that the knowledge representations created by the students were of three types: encyclopedic trees, classification trees, and taxonomies.

In the encyclopedic trees the topic was divided into entries (the nodes), which were organized in a tree-like structure according to their degree of generality or specificity. Hierarchy and branching were determined by the students in light of their own analysis of the topic, not always according to conventional categorization appearing in textbooks or instructional materials. About half of the groups (six) created encyclopedic trees (e.g., pre-Colombian cultures, topography and relief).

Classification trees were built as clearly-defined hierarchical descriptions for a topic (e.g., by defining classes, subclasses, instances). Features like conceptual hierarchy, class inclusion, or exclusive branching can be clearly recognized, being these the main "engines" guiding the creation of the trees. Four groups created classification trees (e.g., varied classifications of nature).

The third type of trees were taxonomies. These were similar to the classification trees in their structure but the nodes and links, instead of being defined ad-hoc by the students, according to their own analysis of the topic, they were constructed following conventional taxonomic guidelines found in textbooks or other sources (e.g., insects or plant taxonomies). Three groups produced trees of this kind (e.g., the flower, the human skeleton).

Structural complexity

We analyzed the trees in terms of three structural features: number of levels, branching nodes and terminal nodes. As shown in Table 6 most trees (11) had 4 to 6 levels of depth, from the root to the terminal nodes. The trees were quite complex in terms of branching. Four trees had between 10-15 branching nodes, four trees 20-25 nodes, and in one case 33 branching nodes were defined. Five trees (about 40%) had 10-15 terminal nodes, and seven trees had more than 15 (up to 48) terminal nodes. All these data indicate that the students succeeded in generating trees of considerable structural complexity in terms of depth, branching and number of representational units.

Insert Table 6 about here

Teachers' evaluation

Six teachers who did not know about the K-tree project were asked to evaluate the experimental group's trees. Besides their evaluation of the learning value of the trees, comments on any additional aspect were encouraged.

Five teachers focused explicitly on the students' work, considering it of high learning value, while the sixth teacher focused only on instructional aspects, not mentioning any evaluation of the trees. The teachers reference to the value of the students' work was summarized at three levels:

Knowledge level: The teachers evaluated the trees' content and concluded that the students showed a comprehensive view of the selected topic, and considerable ability to deal with a wide range of concepts and information items.

Skills level: The teachers considered that the trees show remarkable ability to organize ideas and issues, and mastery of the tree-building process (e.g., gathering, analyzing, organizing information; computer work).

Motivational level: In the teachers opinion the trees reflect the students' high level of motivation required to develop the representations and to cope with large quantities of information.

Two teachers focused on what they interpreted was the instructional plan behind the tree-building activity. They concluded that the teacher must have followed a cooperative-work strategy called "puzzle". By this strategy the tree structure is used as an aid for teaching a topic and its sub-topics or concepts; each student or group of students has to deal with one of these sub-topics contributing to the completion of the whole conceptual puzzle.

The two teachers were critical about what they thought was a weak implementation of the technique. They suggested that the trees were not conceptually "right," indicating that the teacher failed in doing the appropriate planning (e.g., topic analysis, division in themes, sub-themes, causal relationships). In other words, they could not conceive of the trees as the result of the students' own learning (analysis and reconstruction of the topic) but saw them as a reflection of a (deficient) teaching plan. They did not consider the possibility that the representational tree structure was given to the students as learning and thinking tool.

Discussion

The results presented in the previous section will be discussed referring to the three research questions .

Can Representational Skills and Structures be Taught?

A similar question was raised in previous work (e.g., Falmagne, 1990; Mioduser, 1990). The preliminary conclusion in these studies was affirmative. The present study definitely reinforces the claim that representational skills and structures can be successfully taught, this time for an additional age-level (6th graders), and about an additional representational structure (tree-like representations). The students in the experimental group developed reasonable mastery of the skills and the process of creating a structured representation of knowledge, up to the level of building and successively refining their computerized version of the representations. Their awareness of the potential implied in the mastery of such an intellectual tool was reflected in their subsequently written and verbal comments about its value as general tool for learning, planning and decision making.

How Does the Involvement in Constructing Computer Knowledge Bases Affect the Students' Ability to Analyze, Organize, and Structurally Represent Knowledge?

The results of the pre- and post-assessment show a considerable improvement the abilities to analyze, organize and represent knowledge. The analysis of the student representations centered on two main features. The first was the organizational template implied in the written part of the representation. We used a five-level scale for characterizing the templates: Enumerative, spatial, functional, semi-structured and structured representations. The second feature we analyzed was the representational template implied in the visual part of the representation. We used a three-level scale for this purpose: Realistic illustration, conceptual illustration, and formal representation.

At the pre-assessment, most students generated an "enumerative" written representation. By this approach the result was a list of items lacking any organizational structure, any indication of relations among the items, or definition of differential status for the items (e.g., class inclusion). In contrast, only a third of the students created enumerative representations at the post-assessment. Of particular interest were the results at the higher end of the scale, about the ability to generate formally structured (written) representations. This ability was shown by about one third of the students in the post-assessment, compared with only one student in the pre-assessment.

The use of a representational formalism in the visual representations shows a similar, even if slight, improvement in mastery. Most students did what we classed as realistic illustration in the pre-assessment, and no one used any formal notation or structure. At the post-assessment two thirds of the students still produced realistic illustrations, even some of those who at the written level produced formal representations. But in addition, about a quarter of the students produced tree-like diagrams or other representational structures.

It was evident in comparing the representations of the pre- and post-assessment that while the number of items or components in the representations did not vary, what did vary was their nature (e.g., items representing categories, or functions), and their configuration within the representation (e.g., hierarchy, significant links, generality and specificity).

The issue of the cognitive robustness of the representational structure recently acquired (namely, the extent to what the student (a) is aware that s/he possesses this intellectual tool and (b) is able to consider when and how it is appropriately used) was beyond the scope of the present study. But the post-assessment data may serve as the basis for some observations regarding this issue. The results show that even after completing a successful process of learning and applying representational skills, only about half of the students used a formal representational structure in the post-assessment. An obvious conclusion is that, as with any other set of skills for which transfer is expected, repeated activation in new and different situations may better the prospects for an improvement in mastery of these skills. But another clear conclusion is the need to perform continuation studies to trace the consolidation process of representational skills through recurrent and diverse experience.

What Is the Quality of the Knowledge Bases the Students Are Able to Create?

The students created quite complex trees, according to the different parameters which we used to analyze them. Judging by structural parameters, the trees were of considerable complexity in terms of depth (number of levels), branching and number of representational units. The mean number of nodes in the trees was about forty, and the mean number of levels was five. That means that the students were able to identify and define an average number of forty significant information units within a topic, and a five-level network of links among these units. Furthermore, some nodes were enriched with attached information which had to be identified according to its relevance to these particular nodes. This structural complexity evidences the high level of mastery of the representational process achieved by the students.

The different types of trees produced revealed another facet of the quality reached. Only three of them were of the taxonomic kind, and the remaining ten were either encyclopedic or classification trees. Taxonomic trees can be found occasionally in science textbooks. A reasonable assumption is that they could serve the students as a (known) model for developing the trees. But most students developed trees for which they had to define their own criteria for defining categories and representational units, links, levels of specificity, and hierarchical configuration.

The value of the students' work was also assessed by a group of teachers who neither were involved in the experiment nor taught at the experimental group's school. The teacher evaluation pointed out the merits of the students' work, remarking its high value and quality at the knowledge, skills and motivation levels.

Concluding remarks

In this final section we would like to complement the previous conclusions of the study with a brief elaboration on four issues: the need for explicit instruction, the design of the instruction, the role of technology, and further research questions.

Need for explicit instruction. It was suggested that common declarative and procedural representational structures (Mioduser, 1990; Wideman & Owston, 1993), abstract schemas (Ohlsson, 1993) or epistemic forms (Collins & Ferguson, 1993) may be powerful tools to be acquired along with the facts, concepts, methods, and theories the students learn. A key question to be addressed is if these cognitive constructs can be acquired implicitly (while performing learning tasks), or should be explicitly taught The approach adopted in the K-Tree project is the explicit teaching of the cognitive tools, among others for two main reasons. The first relates to the complexity of these tools, and of the cognitive processing required for them to reach the status of generic or abstract schemas. This processing should be supported by explicit guidance, and by appropriate learning opportunities. The second main reason is that these constructs are after all intellectual artifacts. Most of them were devised by cognitive scientists for research purposes (e.g., modeling cognitive processes or creating computational models of these processes). It is unreal to expect that young children will naturally and spontaneously come to discover constructs which resulted from rigorous scientific endeavors. The results of the present study indicate that these symbolic structures can be taught, enabling students using them in the context of instructional tasks to perform at the higher band of cognitive processes.

The design of the instruction: Another issue to be solved is how the students acquisition of these tools should be supported. An alternative phrasing of the question is how to bridge between the expectation for these tools to be mentally constructed as generic as possible (e.g., for augmenting their potential of application in a wide range of domains or issues), and the situated or context-related nature of learning (Collins et al., 1989). The approach adopted in the K-Tree project was to design the instructional sequence in three stages. In the first stage the students learn about the features of the representational structure (e.g., trees) while working with provided examples (i.e., the dinosaurs tree). In the second stage their were asked to construct their own representation, on a subject of their choice. In the third stage alternative instantiations of the generic structure for varied purposes (e.g., decision trees) were discussed. Several interventions of the students at the summary discussion reflected their perception of the tree as a generalizable representational schema. Their suggestions included not only additional content areas for developing taxonomies or encyclopedic trees (as in previous instructional tasks) but more significantly, additional purposes or functions not mentioned during the instruction: building decision trees, representing a game structure, parsing mathematical expressions.

The technology. Much has been written about the relationship between technology and learning processes (e.g., Pea, 1985; Salomon, Perkins & Globerson, 1991). Technologies applied to instruction (e.g., computer courseware, computer text graphic or number processing, microcomputer-based laboratories) may play varied roles (Mioduser, in press). Examples are: extending and complementing cognition (e.g., doing calculations), triggering cognitive processes (e.g., solving problems), or supporting the development of new and unique skills which were not relevant for previous technologies (e.g., programming, querying data-bases, controlled simulation of a system's behavior). In the reported study technology comprises of computer and printed materials. The target skills are the analysis, formal modeling and representation of a body of knowledge and its transformation in a computer knowledge-base. The learning environment plays varied roles: It guides the student in constructing the tree-like representations (e.g., by its tree-building engines, linkage-creation mechanisms); and it supports the student in searching and using the knowledge (e.g., by its browsing mechanisms). Moreover, it supports the gradual building of the skills, following the scaffold metaphor (Brown & Palinscar, 1989). At the initial set of sessions, both the building and consulting of the knowledge-bases is fully supported by the student booklet activities and the computer tool features and mechanisms. Gradually more open-ended tasks appear, and at the second booklet students are explicitly taught programming rudiments and data templates acquiring direct control over the tree representation (and editing if needed) in the computer's memory. Many initial supporting features were by now removed and the students work using transparent and more generic tools (e.g., variables and lists, nested lists, "list-surgery" procedures). The obvious expectation is for these skills and tools to be better candidates for transfer than the initial context tailored ones.

Research issues. This study focused on the students' work with a particular construct, namely, tree-like representations. Following the foregoing conclusions and remarks, a series of continuation issues deserving deep and systematic inquiry can be suggested: The repertoire of symbol structures (e.g., representational structures, epistemic forms, abstract schemas) which are better candidates for teaching should be defined; The appropriateness of different structures for different age levels and populations should be assessed; The learning and application process of these intellectual tools should be traced; And the refinement process of these schemas once acquired and repeatedly used should be studied, along with their cognitive robustness.

Particular questions arise from the use of computers as part of the learning environment. Knowledge representation is a key issue in computer science. In this context it has earned a great deal of theoretical consideration and many technical and programming solutions were developed for it. It seems only natural for this body of knowledge to be recruited to assist the development of appropriate learning environments of representational skills. This study shows the worth of educational shells as learning tools, indicates that more such tools should be developed and that their educational potential be further examined.

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Table 1: Range, mean and mode of student responses for "number of items" at pre- and post-assessment

			Control	
	pre	post	pre	post
Range	**4-40**	**7-41**	**0-32**	**4-17**
Mean	**18.57**	**18.91**	**11.43**	**9.97**
Mode 10 to 20 items	**14** (40%)	**18** (51.4%)	**18** (43.9%)	**20** (48.7%)

Table 2: Frequency distribution of student responses for "mention of criterion" at pre- and post-assessment

	Mention of criterion			
	experimental		control	
	pre	post	pre	post
no	**28** (80%)	**21** (60%)	**40** (97.6%)	**41** (100%)
yes	**7** (20%)	**14** (40%)	**1** (2.4%)	**0**
Total	**35** (100%)	**35** (100%)	**41** (100%)	**41** (100%)

Table 3: Frequency distribution of student responses for “organizational template” at pre- and post-assessment

	experimental		control	
	pre	post	pre	post
enumerative	**24** (68.6%)	**13** (37.1%)	**12** (30.7%)	**13** (32.5%)
spatial	**4** (11.4%)	**5** (14.3%)	**26** (66.6%)	**23** (57.5%)
functional	**4** (11.4%)	**4** (11.4)	**1** (2.6%)	**4** (10%)
semi-structured	**2** (5.7%)	**1** (2.9%)	**0**	**0**
structured	**1** (2.9%)	**12** (34.3%)	**0**	**0**
Total	**35** (100%)	**35** (100%)	**39** (100%)	**40** (100%)
mean SD	**1.6** **1.1**	**2.8** **1.8**	**1.71** **.51**	**1.77** **.62**

Table 4: Frequency distribution of student responses for "representational template" at pre- and post-assessment

	experimental		control	
	pre	post	pre	post
realistic illustration	**32** (91.4%)	**24** (68.6%)	**36** (87.8%)	**37** (90.2%)
conceptual illustration	**3** (8.6%)	**3** (8.6%)	**5** (12.1%)	**4** (9.75%)
formal	**0**	**8** (22.9%)	**0**	**0**
Total	**35** (100%)	**35** (100%)	**41** (100%)	**41** (100%)
mean SD	**1.1** **1.5**	**1.5** **.85**	**1.1** **.33**	**1** **.3**

Table 5: Within and between groups pre- and post-assessment differences for "organizational template" and "representational template"

	comparison		df	t	p
organizational template	exp/pre	exp/post	34	4.19	<0.01 *
	cont/pre	cont/post	38	-0.388	0.7002
	exp/pre	cont/pre	32	-0.61	0.7939
	exp/post	cont/post	33	3.615	<0.01 *
representational template	exp/pre	exp/post	34	3.17	<0.05 *
	cont/pre	cont/post	40	0.443	0.6603
	exp/pre	cont/pre	34	0	-
	exp/post	cont/post	34	3.311	<0.01 *

(exp) experimental group (cont) control group (*) significant difference

Table 6: Structural characteristics of the students' trees

	min	max	mean	from a total of 13 trees:
# of levels	3	7	5.15	11 trees -> 4 to 6 levels
branching nodes	5	33	18.38	4 trees -> 10 to 15 nodes 4 trees -> 20 to 25 nodes
terminal nodes	8	48	19.46	5 trees -> 10 to 15 nodes 7 trees -> more than 15

Figure captions

Figure 1 Structure allowed by the tree

Figure 2 Learning sequence of the experimental group

Figure 1 Structure allowed by the tree

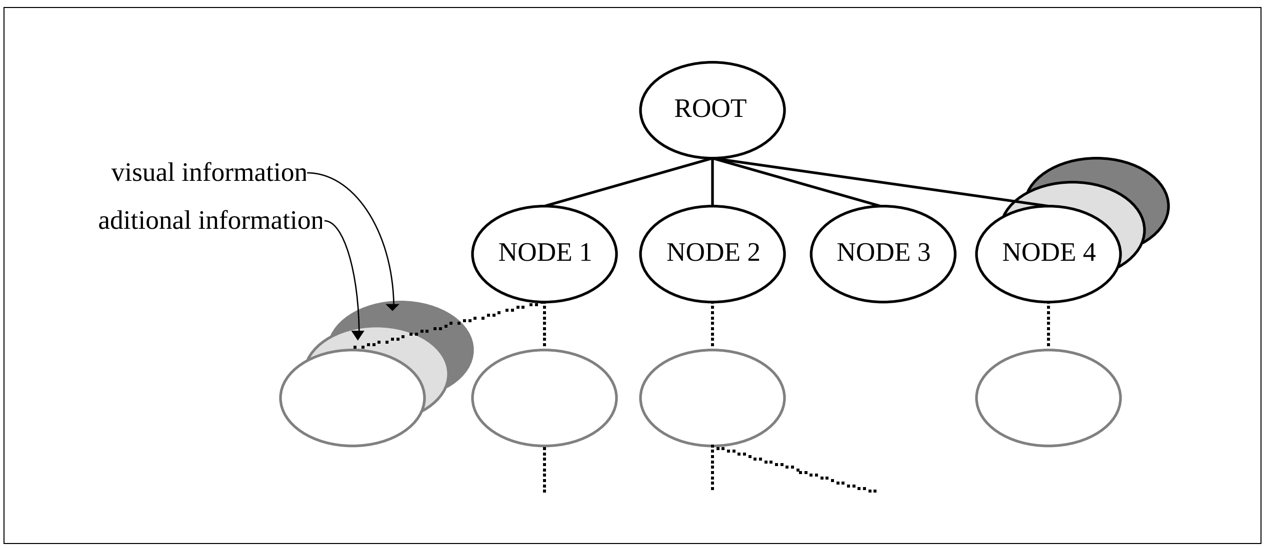

Figure 2 Learning sequence of the experimental group

Stage	Concept / skill	Activity
Creating organized descriptions	Description; classification	Work with objects from the near environment. Gradual progression: descriptions to trees.
Category formation	Properties; similarity; differences; categories	
Defining hierarchy and structure	Level of specificity; class inclusion	
Constructing tree structures	Nodes; branches; leaves	
Creating a tree	Identify properties Define categories Define hierarchies Define nodes and branches	First formal task on tree construction. Creating a tree for a set of 20 dinosaurs.
Creating a knowledge-base	Collect information Define information units Define hierarchical structure Create tree	Complete process from topic definition to developing the computer tree.