Essential issues for the Design of Open Learning Environments emerging from a field evaluation study

Maria Kordaki* **and Nikolaos Avouris**
Human-Computer Interaction Group
Electrical and Computer Engineering Department
University of Patras GR-26500 Rio Patras, Greece
email : Maria.Kordaki@cti.gr, N.Avouris@ee.upatras.gr

Abstract
This study presents a framework for the evaluation of open learning environments integrating methodologies both from Education and from Human Computer Interaction. This framework emphasize, the role of field studies using real students, the formation of hypotheses using qualitative methodologies to analyze the field data and task analytic methodologies namely: Hierarchical Task Analysis (HTA) and Goals, Operators, Methods and Selection Rules (GOMS) which are representative methodologies as interpreted in the constructivist context of learning. In this framework a case study regarding the evaluation of an open learning environment is also presented. The results that emerged from this study document the role of the constructed evaluation framework in illuminating essential learning and usability issues regarding the design of open learning environments. These issues can help designers to form a more student centered view in the design of such environments.

1. Introduction

Open learning environments can play a crucial role in the learning process. Well known examples of these environments such as Cabri Geometry, the Logo language environment, Interactive Physics, have given us evidence regarding their significant mediation in the learning process (Papert, 1980; Laborde & Srasser, 1990; Noss & Hoyles, 1996; Jimoyiannis & Komis, 2001). In these environments learners have the opportunity to solve both well and ill-defined problems by selecting among a variety of tools those most appropriate for their cognitive development. In this way learners can express their inter- and intra-individual differences (Kordaki & Potari, 2002). Designers of open learning environments are inspired by constructivist views of learning taking also into account social considerations regarding the role of tools in the learning process (Papert, 1980; CTGV, 1991; Noss & Hoyles, 1996, Duffy, Lowyck & Jonassen, 1993). These views emphasize the active, subjective and constructive character of knowledge (von Glasersfeld, 1987) as well as the role of knowledge collaboration and the role of computer tools as cognitive tools in the learning process (Vygotsky, 1978; Noss & Hoyles, 1996; Jonassen, Carr & Yueh, 1998). The role of both authentic problem solving activities and contexts as well as the manipulation of primary sources of data is also acknowledged (Jonassen 1991; Lemerise, 1992; CTGV, 1992; Kordaki & Potari, 1998a). These authentic contexts can motivate learners by providing them with opportunities to control their learning and to form their own goals. Constructivism also stresses the need for using the learners' previous knowledge as a base line for building on his/her own knowledge while errors are considered as opportunities to learn. In addition, the availability of possibilities for the development of multiple perspectives of a concept, are viewed as

* Corresponding author, fax: +30-61-997316, email: Maria.Kordaki@cti.gr

opportunities for the expression of learners' inter- and intra-individual differences (Lemerise, 1992; Kordaki & Potari, 2002).
A discussion has been developed about the interpretations both of constructivism and of social views of learning in design specifications of open learning computer environments (Papert, 1980; Jonassen, 1985; Laborde & Strasser, 1990; Reigeluth, 1991; CTGV, 1991; Duffy & Jonassen, 1992; Duffy, Lowyck & Jonassen, 1993). Modeling processes are also used in the design of these environments. More specifically, early models regarding the learning process, the subject matter and the possible learners' behavior in facing appropriate tasks are constructed. These early models express the designers' views about the above topics as he/she interpreted the respective literature. Despite the fact that this design process can be well documented by the designers of these environments, learners often solve problems in unforeseen ways (Squires & Preece, 1999). In addition, serious usability issues regarding the learners' real behavior in using the provided tools can be illuminated. This fact establish the role of qualitative field evaluation studies using real learners for a complete design of these environments as essential (Owston & Dadley Marling 1986; Gunn, 1995). In the said studies both cognitive and usability issues regarding the use of the provided tools need to be investigated. Despite this fact, evaluation studies are often realized using research methodologies from the area of educational research in isolation from methods that emerged from the area of Human Computer Interaction. Qualitative methodologies (Cohen & Manion, 1989) and more specifically, phenomenographic methodologies (Marton, 1988) are widely used to study educational practices. These methodologies stress the study of learners' behavior as expressed through his/her actions. In addition, specific methodologies emerging from HCI propose Task Analytic methodologies such as Hierarchical Task Analysis (HTA) and Goals, Operators, Methods and Selection Rules (GOMS) methodology (Kieras, 1996; Kieras & Kieras, 1996; Card, Moran & Newell, 1983). The key feature of this methodology is the definition of the high level *goals* of the user, split into sub-goals necessary in order to accomplish these goals. The *operators* are the actions that the computer environment allows the user to perform (menu – selections, direct manipulation operators etc.). *Methods* are well-learned sequences of sub - goals and operators which can accomplish a goal. Finally *selection rules* are the personal rules that the users follow in deciding what method to use in particular circumstances. By using methodologies coming from the previously referred to areas in combination, the designers' model about the students' behavior regarding both the learning of the subject matter and the use of specific tools can be constructed. In this study we attempt to provide a framework for the evaluation of open learning environments integrating the previously referred to different methodologies. Moreover, an interpretation of the Task Analytic methodologies in the constructivist learning context is attempted. Finally, we use this evaluation framework to define design principles of open learning environments. Design principles which emerged from such studies are not yet reported. The open learning environment that was used was C.AR.ME. microworld (Kordaki & Potari, 1998b). This environment is constructed to support students in their learning of the geometrical concepts of Conservation of Area and its Measurement.
In the rest of this paper we present: firstly, our modeling process in interpreting constructivist and social views of learning in design specifications of the C.AR.ME. microworld. Secondly, the theoretical framework and the specific evaluation methodology used. Thirdly the analysis and the interpretations of the data which emerged from this evaluation study. Next a discussion of the design principles which

emerged both from the initial design and from the results of the evaluation experiment. Finally, we conclude by emphasizing the essential issues for the design of open problem solving environments, which emerged from this experiment.

2. The initial design of C.AR.ME.

The initial design of C.AR.ME emerged as a synthesis of three models of theoretical considerations: one relating to learning, second, to the subject matter and third, the model of learners' possible actions in performing essential tasks for the learning of subject matter (Kordaki & Potari, 1998), as outlined in table 1.

The 'learning' model	
Theoretical considerations	Design principles
The active role of the learner	• Interactivity of the environment • Availability of tools
The subjective character of learning	Availability of tools: • to construct different representations of the concepts to be learned, • to help students construct and study their own computational objects related to the concepts to be learned
The constructive character of learning	Availability of tools: • to explore the knowledge of others e.g. simulations, computational objects • to be used in solving different problems • to be used in making constructions acquiring hands - on experience related to the subject matter, • to give intrinsic visual feedback on learners actions
The model of the 'subject matter'	
Students can construct the concept of conservation of area actively, by splitting areas into parts and recomposing these parts to produce equivalent areas	Tools to simulate human actions to split and recompose areas : tools to copy, cut, past, rotate and symmetry entire areas or parts of them
Students can construct the concept of conservation of area in a more abstract way by exploring it in a number of different dynamic representations of equal areas	Tools to automatically transform areas to other equivalent ones of standard geometrical shapes
Students can construct the concept of conservation of area in a more abstract way by exploring it in classes of equal areas of the same form	Tools to automatically produce classes of equivalent areas of the same form such as equivalent triangles and parallelograms
Students can construct the concept of area measurement by splitting areas into a variety of area-units and recomposing these units to produce equivalent areas	Tools to represent a variety of units or grids (square, rectangular and student's unit and grid respectively)
The model of tasks	
The task of comparison	By measuring areas : • automatically (named as strategy C1) • using area units or grids (named as strategy C2) By superimposing areas using : the copy, cut, past, rotate and symmetry tools (named as strategy C3)
The task of transformation	Transforming areas: • automatically (named as strategy C4) • by splitting areas in parts and recomposing them to produce equivalent shapes using the copy, cut, past, rotate and symmetry tools (named as strategy C3) • using area units or grids (named as strategy C2)

Table 1. From theoretical considerations to design principles during early design

The construction of the first model reflects the designers' interpretations both of constructivist and social views for learning. The construction of the second model was based on the literature regarding the definition of what is to be learned and how students can learn it. The selection of the appropriate tasks for the learning of the subject matter is also based in the literature. All these models reflect the designers' views about the relative topics. These early models are presented in Table 1. In the left column of this table the educational theoretical considerations selected for the design of this microworld are presented, while in the second column the interpretations of these considerations in terms of software design specifications are included. According to the design principles described above the C.AR.ME. microworld (Kordaki & Potari, 1998b) has been developed. This microworld provides the students with opportunities to approach the geometrical concepts of conservation of area and its measurement in a variety of different ways. More specifically, students can select among a variety of tools the most appropriate for their cognitive development to construct a variety of solution strategies to face appropriate problems. Four categories of students' strategies were foreseen by the designers of C.AR.ME. (Categories, C1, C2, C3, C4, in Table 1) as possible.

3. The evaluation experiment

The theoretical framework and the method of the study

The field study was designed to evaluate the effectiveness of this early design by exploring students' thinking on the basic concepts to be learnt – the concepts of conservation of area and its measurement- as well as students' interactions with the software. The frame work of this study integrates methodologies coming from different areas: First, we used the qualitative research educational methodology (Cohen & Manion, 1989) adopting also a phenomenographic approach to evaluation (Marton, 1988) as well as Grounded Theory (Babbie, 1989) to analyze the students' learning approaches to the subject matter and to form hypotheses about their thinking based on the data coming from the field experiment. Second, we used task analytic methodologies: Hierarchical Task Analysis (HTA) and Goals, Operators, Methods and Selection Rules (GOMS) methodologies (Kieras, 1996; Kieras & Kieras, 1996; Card, Moran & Newell, 1983). Here these methodologies were used to represent the learning goals of real students as these goals emerged from the field data using the previously described educational methodology. The specific interactions with the software needed to perform these goals consisted of the experts' interactions in order to realize the students' specific goals. Below the method used for this evaluation study is presented in steps regarding the following issues:

1) *The educational focus of the study*. This study focuses on the strategies developed by the students to face essential tasks for the learning of the subject matter.
2) *The criteria for the task assignments*: The criteria for the construction of the given tasks were that they should be a) appropriate for the learning of basic concepts related to the subject matter as it emerged from the literature b) solved in a number of different ways c) ill- defined so that each student can give personal meanings to these tasks and d) to be original regarding the learning of the subject matter e) appropriate for the age of the learners. According to these criteria, two tasks were assigned to the students : first the transformation of a non convex polygon to another shape with equal area and second, the comparison of a non convex polygon to a square. Students were asked to face both tasks 'in any possible way' (Hiebert, 1981; Driscoll, 1981; Lemerise, 1992; Kordaki & Potari, 2002).

3) *The context of the study*: Here a number of decisions were realized regarding the age and the number of the participants in the study as well as the duration of the study and the number of computers needed. 30 students from the 8^{th} grade (14 years old) was selected. These students worked in rotation in a computer lab consisting of three computers. The duration of this study followed the students needs and lasted about two hours per task.
4) *The familiarization with the provided tools:* A familiarization phase was designed to familiarize the students with the tools of C.AR.ME. and not to get them involved in the processes of solving the specific tasks of the main study.
5) *The role of the participants.* The researcher participated in the study with minimum intervention. The aim was to illuminate the effectiveness of the software regarding the students' learning and the usability of the provided tools and not reflect the researchers' ideas.
6) *The data resources.* The data resources are a) log files containing the students interactions with the software b) electronic snap-shots of students drawings c) audio taped discussions between the participants during this experiment and d) field notes of the researcher. The variety of types of data are expected to give a more complete view of the whole experiment.
7) *Data analysis and classification.* This process followed the following steps : a) The various types of data were organized according to the two different tasks. b) In each task all individual students' multiple-solution strategies were identified and reported c)These strategies were analyzed in terms of students conceptions of the concepts to be learned and their development as they emerged during the experiment d) These strategies were analyzed in terms of tools and software interactions that users needed to perform them e) In the next stage the focus was on the entire group of students and a classification of strategies into categories was constructed. The criterion for this classification was the kind of tools used by the students to construct each strategy.
8) *The modeling process.* This process followed the following steps : a) for each individual task, each individual category of students' strategies was represented using Task Analytic methodologies. The representation of the students' strategies in the key stroke level was realized by accepting the experts' key strokes in performing these strategies. In this way a model of the ideal performance of each specific category was constructed b) for each individual task, the entire group of categories of students' strategies was represented using HTA and GOMS methodologies. In this way a model of the ideal performance of each specific task was constructed. The above models reflect the researchers' professional actions in using the provided tools to perform the strategies that students invented during this experiment. These models also reflect the researchers' views about the students' learning approaches to the given tasks. The last model was constructed in order to be used as an evaluation tool of the software and of students' learning while interacting within it. By using this model a number of modifications of the quality of the software were realized. These modifications related to the usability of the existing tools and the enhancement of the environment with new tools which recognized the students' needs. In addition, each individual student's conceptual map and his/her development regarding the subject mater were represented. Comparisons between the solution strategies performed by an individual student and the solution strategies performed by the entire class of students were also realized. Using the last model the modifications necessary in

the designer's early model were discovered and are discussed in the following section. An example of a part of this model is presented in figure 1. For example the Goal 1.3.2.1. : transforming areas to other equivalent ones by measuring them actively using area units can be performed by using the Operations 1.3.2.1.1. or 1.3.2.1.2. The operation 1.3.2.1.1. can be performed by using the Method described by the steps 1.3.2.1.1.1 until 1.3.2.1.1.5. The step 1.3.2.1.1.1.1 can be performed by selecting among the Selection Rules 1.3.2.1.1.1.1. until 1.3.2.1.1.1.1.3. A more thorough discussion of usability analysis of the C.AR.ME tools, using this approach is included in Tselios, Avouris & Kordaki (2001; 2002).

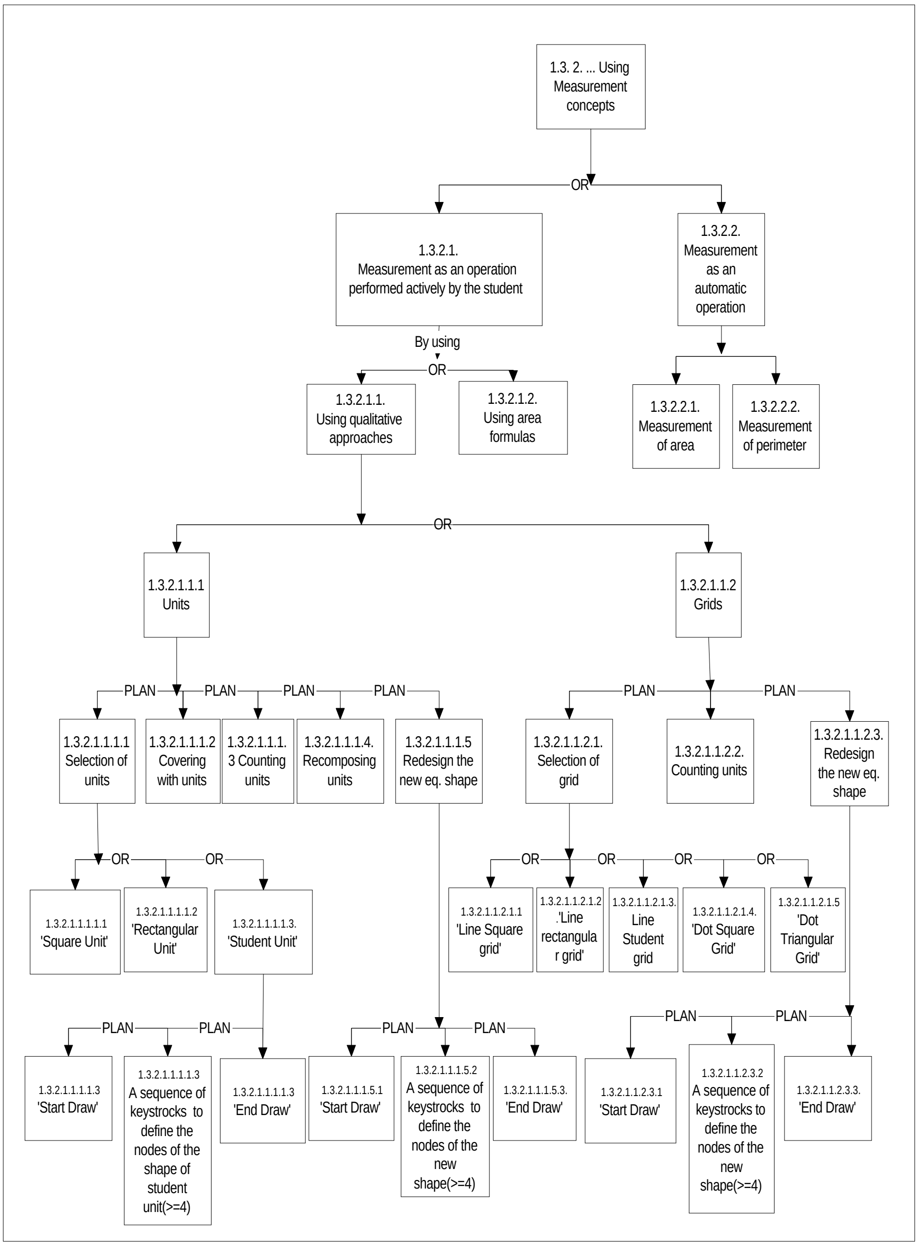

Figure 1. Task analysis of the transformation task using measurement concepts

4. Analysis of the results of the evaluation experiment

The variety of different tools provided by the C.AR.ME microworld as well as the nature of both tasks, which students were asked to perform 'in any possible way' stimulated the students into devising a plethora of solution strategies to these tasks (Kordaki & Potari, 2002). These strategies were classified in twenty eighth categories for both tasks, the criterion being the tools used by the students (Kordaki & Potari, 2002). From these, twenty distinct strategies were identified, despite the fact that only four (4) solution strategies to these tasks were foreseen by the designers of C.AR.ME. according to the early designers' model.

By using the HTA & GOMS methodologies analyzed in the previous section we constructed a model of whole-class problem solving strategies regarding both tasks. In this model the twenty categories of students' strategies were reflected. This model helped us to investigate, the most common strategies performed by the students, each individual student's strategies regarding the given tasks, the essential factors that differentiate the students' behavior foreseen by the designers' of C.AR.ME the behavior observed in the field using real learners and finally essential usability issues regarding the use of the provided tools.

In general, the data of this evaluation experiment confirmed but also extended the principles which emerged from the early design model of C.AR.ME. These data also illuminated essential factors that affected the behavior of the learners compared to the behavior which was anticipated by the designers of C.AR.ME. These essential factors helped us to enhance the early designer-model and are presented below:

Students' previous knowledge. School knowledge about the learning subject (area formulae) was not explicitly supported in this computer environment. This decision was based on the literature, in order to force students to use qualitative approaches to solve the given tasks. Despite this fact, students tried to use this knowledge in their problem solving approaches (Six unforeseen strategies were identified). As a result these students were faced with difficulties in using this knowledge in this environment. This fact lead us to consider the design of extra tools to be used constructively by the students to express their previous knowledge.

Students misconceptions regarding the learning subject. Students' misconceptions were revealed in this computer environment e.g their confusion between the area and the perimeter of a shape. As a result a need to design tools to handle these misconceptions emerged.

Students used the provided tools in combination. Students used tools that support different approaches to the given tasks in interrelation (eleven unforeseen categories of strategies were constructed) e.g. they transformed areas by splitting them in parts and recomposing the parts to form equivalent shapes. Then they transformed automatically these transformed shapes to other equivalent ones. The plethora of the provided tools inspired the students to combine them in a variety of ways. This fact demonstrates the need for robust ant interoperable tools.

Students invented unanticipated methods to solve the given tasks. Students developed methods not anticipated by the designers of C.AR.ME. to tackle the given tasks (four unforeseen strategies were constructed). This fact leads us to consider the design of new tools, for example, a tool to enclose a non convex polygon in a minimum superset.

Students expressed a need for new tools, eg. to use right-angled triangular grids to measure the given areas more accurately.
Students expressed a need for self evaluation tools. Students used the tools to automatically perform the given tasks, as self evaluation tools. This fact lead us to consider the design of self evaluation tools in computer environments.
Students expressed the need for a *more explicit relation between the non transparent tools* (eg. automatic transformations) *and the background concepts* that govern their behavior.

Essential usability issues emerging from the field study.
Comparing the experts' sequence of actions in performing the students' goals with those performed by real learners, a number of issues reflecting poor usability were identified. These issues are listed below:
Tools that simulated students sensory-motor actions. A particular area of poor usability was that of the tools that simulate human actions in splitting areas into parts and recomposing the parts to produce equivalent shapes, namely: the cut, paste, rotate, and symmetry tools.
Tools that support the iteration of units. Students had difficulties in their attempts to manipulate a unit in order to cover an area without gap or overlaps.
The inter-operability of the provided tools. As the provided tools were designed to be used in isolation, a number of usability issues arose when students used them in combination.

5. Discussion and Conclusions

This study proposes a framework for the evaluation of open learning environments combining different methodologies. On one hand a qualitative methodology and more specifically phenomenography from Education and Hierarchical Task Analysis (HTA) methodology from Human Computer Interaction have been combined. The main aspects of this methodology consist of : field work with real students, selection of appropriate tasks, definition of the educational focus of the study, definition of the roles of the participants - the role of the researcher as observer, collection of a variety of types of data, analysis and classification of data to form hypotheses about students' learning goals and actions, use of HTA to model task performance. This performance consists of the specific goals of the entire group of learners realized by the actions of an 'ideal' user.
To demonstrate the proposed framework, an evaluation experiment of the open learning environment, the C.AR.ME. microworld, took place. The model of learners' goals in facing appropriate tasks was constructed in the frame of the experimental study. By studying this model a number of essential results emerged to be used in the design of open learning environments. More specifically, the analysis of the data shows :

First, that learners were stimulated to construct a plethora of solution strategies not anticipated by the phase of the initial design of this open environment. The variety of the provided tools and the nature of both tasks to be solved 'in any possible way' stimulated the learners to build diverse solution strategies. In the process of performing these non anticipated strategies a number of unanticipated usability issues regarding the tools arose. Usability issues were also illuminated in using the provided

tools to perform the expected strategies as the behavior of the users with new tools is not easily anticipated during design. In addition, the nature of the specific tasks played a crucial role in the definition of the specific tools needed by the students.
Second, in the design of open problem solving environments appropriate tools can be designed to help learners to :

- express their prior knowledge
- overcome basic difficulties regarding the subject matter
- develop methods of self evaluation
- gradually explore the hidden information included in non-transparent representations
- attempt to use the provided tools in combination

Third, field studies can illuminate the need for extra tools in relation to specific tasks.

Finally, 'early' design of open learning environments is not enough despite the fact that this design can be based on the study of established theoretical considerations. The reported study shows that field evaluation is necessary in enhancing the 'early' principles of the design of these environments. These new principles can be exploited in the general design of open problem solving environments. Moreover, the use of task modeling methodologies in combination with educational qualitative methodologies is very useful in the construction of the model of the learners' behavior regarding both learning and usability issues. The specific way of using the above methodologies to construct this model makes it a suitable evaluation tool. This tool has helped us in reaching conclusions about learning and usability issues that have general implications for other similar open problem solving environments.

Acknowledgements: Special thanks are due to Despina Potari and Nikos Tselios who participated in forming ideas and processing the field data, as well as building tools to support the framework.

6. References

Babbie, E. (1989). *The Practice of Social Research.* CA: Wadsworth Publishing Company.

Card, S.K., Moran T.P., & Newell A. (1983). The Psychology of Human-Computer Interaction, Lawrence Erlbaum, Hillsdale, N.J.

Cognition and Technology Group at Vanderbilt (CTGV) (1991). Some Thoughts About Constructivism and Instructional Design. *Educational Technology*, Sept. 1991, 16 -17.

Cognition and Technology Group at Vanderbilt (CTGV) (1992). Emerging Technologies, ISD, and Learning Environments: critical Perspectives. *Educational Technology Research and Development*, 40(1), 65-80.

Cohen, L., & Manion, L. (1989). *Research Methods in Education.* London: Routledge.

Driscoll, M. J., (1981). Measurement in Elementary school Mathematics. In *Research Within Reach* (pp. 29-36). Reston, VA: CEMREL, Inc.,N.C.T.M.

Duffy, M. T. & Jonassen, H. D. (1992). *Constructivism and the technology of instruction: a conversation,* Hillsdale, NJ: Lawrence Erlbaum Associates.

Duffy, M. T., Lowyck, J & Jonassen, H. D. (1993). *Designing environments for constructive learning*, Berlin: Springer-Verlag.

Hiebert, J. (1981). Units of measure: Results and implications from National Assesment. *Arithmetic Teacher, 28* (*6),* 38-43.

Gunn, C. (1995). Usability and beyond: Evaluating Educational effectiveness of computer-based learning. In G. Gibbs (Eds), *Improving Student Learning Through Assesment and Evaluation* (pp. 168-190). Oxford Centre for Staff Development.

Jimoyiannis, A., & Komis, V. (2001). “Computer Simulations in Teaching and Learning Physics: a case study concerning students’ understanding of projectile motions”, *Computers and Education*, February 2001, vol. 36, pp. 183-204

Jonassen, D. H. (1985). Learning Strategies : A New Educational Technology, *Programmed Learning and Educational Technology,* 22(1), 26-34.

Jonassen, D. H. (1991). Objectivism versus constructivism: do we need a new philosophical paradigm? *Journal of Educational Research*, 39 (3), 5-14.

Jonassen, D. H., Carr, C. & Yueh, H-P. (1998). Computers as Mindtools for Engaging Learners in Critical Thinking. *Tech Trends* 43(2), 24-32.

Kieras, D. (1996). Task analysis and the design of functionality, in CRC *Handbook of Computer Science and Engineering*, CRC Press.

Kieras, B.E. J., & Kieras, D. E. (1996). Using GOMS for User Interface Design and Evaluation: Which Technique?, *ACM Trans. On Computer-Human Interaction*, vol 3, no 4, pp. 287-319.

Kordaki, M., & Potari, D. (1998a). Children's Approaches to Area Measurement through Different Contexts. *Journal of Mathematical Behavior*, 17(3), 303-316.

Kordaki, M., & Potari, D. (1998b). A learning environment for the conservation of area and its measurement: a computer microworld. *Computers and Education*, 31, 405-422.

Kordaki, M., & Potari, D. (2002). The effect of area measurement tools on children’s strategies : the role of a computer microworld. *International Journal of Computers in Mathematical Learning, 7(1), 1-36.*

Laborde, J-M., and Strasser, R. (1990). Cabri-Geometre: A microworld of geometry for guided discovery learning. *ZDM, 5,* 171-177.

Lemerise, T. (1992). On Intra Interindividual Differences in Pupils's Learning Styles. In C. Hoyles and R. Noss (Eds), *Learning Mathematics and Logo* (pp. 191-222). Cambridge, Ma: MIT Press.

Marton, F. (1988). Phenomenography: Exploring Different Conceptions of Reality. In D.M. Fetterman (Eds). *Qualitative Approaches to Evaluation in Education: The Silent Scientific Revolution*, (pp. 176-205). New York: Praeger.

Noss, R., & Hoyles, C. (1996). *Windows on mathematical meanings: Learning Cultures and Computers.* Dordrecht : Kluwer Academic Publishers.

Owston, G. R., & Dudley-Marling, C.(1988). A criterion-Based Approach to Software Evaluation. *Journal of Research on Computing in Education,* 20, 234-244.

Papert, S. (1980). *Mindstorms: Pupils, Computers, and Powerful Ideas.* New York: Basic Books.

Reigeluth, C. M. (1991). Reflections on the implications of Constructivism for Educational Technology. *Educational Technology*, September 1991, 34 - 37.

Squires, & Preece, J., (1999). Predicting Quality in Educational Software: Evaluating for Learning, Usability and the Synergy between them, *Interacting with Computers*, 11 (1999), pp. 467-483.

Tselios, N., Avouris, N & Kordaki, M. (2001). A Tool to model user interaction in open problem solving environments. *Panhellenic Conference in Human Computer Interaction 2001*, (pp. 91-95), Patras, December 2001.

Tselios, N., Avouris, N & Kordaki, M. (2002). Student Task Modeling in Design and Evaluation of Open Problem-Solving Environments. *Education and Information Technologies*, 7(1), 17-40.

von Glasersfeld, E. (1987). Learning as a constructive activity. In C. Janvier (Eds), *Problems of representation in teaching and learning of mathematics* (pp. 3-18). London: Lawrence Erlbaum associates.

Vygotsky, L. (1978). *Mind in Society.* Cambridge: Harvard University Press.