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Constructivist design and evaluation of interactive educational software: a research-based approach and examples

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Abstract

The paper introduces constructivist views of learning as a theoretical background to inform the design, implementation and evaluation of quality interactive multimedia educational software. It reviews various constructivist views of learning and also constructivist technology-mediated learning. It proposes an approach to design and evaluation of constructivist educational software, which is based on research in students' ideas, and comprises three stages: a) initial research into students' existing ideas, conceptions, conceptual difficulties and needs, b) design of the software based on students' conceptions and conceptual needs, and formative evaluation of it, and c) software implementation and evaluation within a constructivist learning environment, based on students' conceptual change and construction of appropriate knowledge by them. This research-based approach is compared to other existing models of design educational software environments. In order to illustrate this approach, two examples of Greek constructivist educational software with science content are briefly presented: *"Interaction between Objects"*, which aims at promoting knowledge construction about mechanical interaction and Newton's laws through interactive simulations of real-life situations and cognitive conflict processes, and *"M.A.TH.I.M.A."*, aiming at promoting construction of multiple, linked appropriate representations about several science topics (free-fall phenomenon, geometrical optics, heat and temperature, electric circuits, molecules and atoms). The proposed approach intends to enhance collaboration between software designers, content education research specialists, teachers and learners, in order to improve the quality of educational software to better respond to students' learning with understanding.

Key words: interactive educational software, constructivism, students' conceptions, software design, software evaluation, conceptual change

Introduction

The last years we witness the information explosion and the enormous impact of Information and Communication Technologies (ICT) in everyday life, work, and learning. Computers have great potential as cognitive tools (Jonassen, 1993). However, these tools can only enhance student achievement if appropriately used (Cognition and Technology Group at Vanderbilt, 1997; Bransford, Brown & Cocking, 2000).

Technology-mediated learning is well investigated, especially in the higher education level to promote students' active learning, qualitative reasoning and conceptual understanding (Jonassen, Mayes & McAleese, 1993; Kanuka & Anderson, 1999). Secondary and primary educational levels should also benefit from those potentials.

In the past, usual teaching and instructional design were typically focused on the teacher planning and leading students through a series of instructional sequences and events to achieve a desired learning outcome (Gagné, Briggs & Wager, 1988).

Typically these forms of teaching refer to organized transmission of a body of knowledge followed by some forms of interaction with the material to consolidate the knowledge acquisition (Hedberg, Oliver, Harper, Wills & Agostino, 2002). Also, technology-enhanced learning models have historically been developed around the transmission and retention of information through taught knowledge and skills, through the de-contextualized acquisition of passive, inert knowledge, and by assuming that reading, watching videos or controlling a button on these page-turners constituted 'active learning' (Young, 2003). In many cases these models failed to recognize the need for application in practice in order to understand how to effectively utilize knowledge (Jonassen, 1994).

The emergence of constructivism as a new learning theory tends to make clear the limits of the 'instructivist' model of learning and to shape new promises to improve teaching and learning in school. It is accepted that the new learning technologies should be informed by constructivist approaches for learning and teaching. These approaches are student-focused rather than teacher-focused, foster student active participation rather than passive attendance, use a variety of instructional tools rather than only print material, promote communication and collaboration among students rather than individualistic and competitive work, and facilitate operational rather than rote learning.

This paper deals with the main issues of constructivist theory of learning, and its impact in the design of constructivist educational computer systems. First it discusses the main theoretical issues and principles of the constructivist approach to learning, and to constructivist technology-mediated learning. It points out the necessity to use several techniques for the investigation and analysis of students' existing conceptions, as well as strategies to cope with students' alternative conceptions, in order to help them construct scientific knowledge. Then it proposes an approach for applying constructivism in the design, implementation and evaluation process of multimedia educational software, which is based on research in students' existing ideas and conceptions about the software's content. This approach is compared to existing models of software design, and it is illustrated by the presentation of two examples of educational software with science content, *"Interaction between Objects"* and *"M.A.TH.I.M.A."*, which have been designed and evaluated according to the proposed approach. Finally, implications for further research and collaboration among the persons involved in this design and evaluation process are discussed, as well as implications for the design of other software environments for distance learning.

CONSTRUCTIVISM AND LEARNING TECHNOLOGIES

In order to address the issue of how constructivism can inform the design of a multimedia educational software package, it is necessary to outline the basic assumptions of this theory and in particular its relations to technologically informed systems for learning.

Constructivist views of learning

A wide variety of educational approaches claim to be constructivist. According to Kunz (2004), in many cases e-learning literature gives the impression that constructivism is a result of the introduction of Information and Communication Technologies (ICT) in education, but in reality constructivism has its roots back in the years 1920s and 1930s of the last century. The work of Jean Piaget put the foundations of this learning theory, extended later by the work of Leon Vygotsky and many more theoreticians. Piaget's 'genetic epistemology' suggested that knowledge acquisition occurs due to two complementary processes, assimilation (when new information is incorporated in the existing cognitive structure), and accommodation (when new information constrains the existing cognitive structure, provokes re-structuring and the formation of a new cognitive structure). The interactions of the child with the material environment play a crucial role in experience acquisition and knowledge construction, and in the development of symbolic entities including language (Piaget, 1929/1967). Vygotsky on the other hand emphasized the influence of social and cultural contexts in learning, cognitive development and knowledge building. He maintained that thought is interiorized language and introduced the concept of 'zone of proximal development', which highlights the fact that when the learner is offered guidance or collaboration s/he is able to develop many more skills than s/he can achieve on her/his own (Vygotsky, 1934/1988; 1978).

Subsequent ideas, which contributed substantially to the development of constructivist learning theories, are: a) Ausubel's idea that the most important factor that influences learning is what the learner already knows. Ausubel advised the teachers to get informed about the learners' prior knowledge, in order to teach them appropriately (Ausubel, 1968), and b) Wallon's idea about the development of scientific thought as a process of evolution of syncretic thought towards categorical thought by the emergence of categories in a previously undifferentiated state of mind (Wallon, 1945/1989; 1970).

The constructivist theoretical paradigm has been formulated after an extent number of research studies brought to light students' alternative conceptions concerning several mathematics and science topics. Constructivist theories support that scientific knowledge is personally constructed by the active, collaborative, reflective involvement of the learner in the pedagogical process, during which s/he interacts with new information, material, tools, persons, and cultural means (Driver & Oldham, 1986; Duit & Treagust, 1986; Driver, 1989a, 1989b; Scott, Asoko & Driver, 1992). Constructivist theories have developed various ideas and principles transferred from cognitive psychology, epistemology and history of science to the domain of learning. For example, an important concept adopted by constructivists, especially of French origin, is 'cognitive obstacle', derived from the concept of 'epistemological obstacle' first introduced by Bachelard (1938/1993). This concept implies the idea that knowledge is constructed by means of discontinuities and cut-offs against common, everyday knowledge, bypassing the obstacles in its course. Common ideas, which may constrain this progress, constitute epistemological obstacles. Science education in particular used the concept of 'cognitive obstacle' or 'didactical learning obstacle' to describe several hard-core conceptions which hardly change with ordinary teaching and require special didactic approaches. In order to overcome those cognitive obstacles, specific pedagogical goals are necessary to define for constructive teaching ((aim-obstacle') (Martinand, 1986).

A number of noteworthy constructivist theories made important theoretical points about the use of constructivism in teaching and learning. In their review, Kanuka and Anderson (1999) remind us of the following theories: *cognitive constructivism* (knowing is an actively constructed individual thought process), *radical or critical constructivism* (reality is only a speculation, or a supposition, or a function of the workings of our cognitive structure and thus a very personal experience), *situated constructivism* (we can know only what is real; knowledge is grounded in the experience; the process of constructing knowledge involves examining and understanding the experience where the process occurs), and *social constructivism* (knowledge is an active process of constructing meanings socially through language and sharing cultural practices). Despite the differences of these stances, each constructivist approach has underlying similarities. Common to each stance is a belief that we construct knowledge based on what we already know (children's mind is no *tabula rasa*) and that learning is an active process of construction rather than a passive process of transmission of knowledge.

Thus, the importance of students' prior conceptions and knowledge and their active involvement in the learning process is crucial for appropriate knowledge construction. A constructivist approach for teaching and learning could be considered as a methodological tool serving a double purpose: the decision-making about the content of the knowledge to be taught and the design of the learning sequences and tasks (design of learning scenarios, simulations, activities, representations, questions, help, feedback, evaluation items, meta-learning strategies, etc.). For this purpose, data issued from three different types of analysis should be considered:

i) Conceptual analysis of students' prior ideas, conceptions, knowledge, skills, models of reasoning, etc., as well as analysis of the actual scientific knowledge in the domain under study may reveal how important is the distance between the two models of thought, the everyday empirical and the scientific thought (Driver, 1989a, 1989b; Martinand, 1986).
ii) Epistemological analysis of the taught knowledge may identify conceptions, ideas, models of reasoning, etc., which have been developed during the historical evolution of scientific ideas. This study may reveal ideas that have many similarities with students' conceptions, which are different from the scientific ones and hardly change with teaching, sometimes functioning as 'cognitive obstacles' (Bachelard, 1938/1993; Martinand, 1986).
iii) Psychological analysis of the existing and the desired cognitive structures may inform the design of the learning tasks. The intellectual tasks should facilitate the development of scientific thought, and more particularly, children's intellectual evolution from concrete operational towards abstract operational thought (Piaget, 1929/1967), the evolution of their thought and language skills by the help of actions scaffolding them in a 'zone of proximal development' (Vygotsky, 1978), and the evolution of their syncretic thought towards categorical thought (Wallon, 1945/1989; 1970).

Those types of analysis can inform the design of the teaching strategies and tools. More specifically, they may inform the design of the scientific content to be studied, the specific teaching goals, which should also cope with students' cognitive obstacles, and the specific cognitive tasks to be undertaken during the various learning activities. The combination of those types of analysis should lead to didactical transposition (Chevallard, 1985/1992), i.e. the transformation of the scientist's knowledge content in order to fit the learner's knowledge and conceptual needs. During construction of scientific knowledge, collaboration and communication fosters negotiation of meaning among co-learners and the teachers, the learners' language is enriched, various point of views clarified and discussed, and eventual cognitive conflict situations promote students' conceptual change.

Thus constructivism should deal with every stage of knowledge construction, and with a variety of learning activities, teaching materials and tools.

Constructivist technology-mediated learning

Since Seymour Papert (1980) declared that computers can be powerful mind tools for children's construction of knowledge, many constructivist learning theories became widely accepted in all fields of education, including the application of technology to teaching and learning. This interest is related to the capacity of computers to provide an interactive environment that creates *"an effective means for implementing constructivist strategies that would be difficult to accomplish in other media"* (Driscoll, 1994: 376).

There is evidence to show that computer systems have the potential to alter the traditional forms of teaching and learning, and serve as cognitive tools (Jonassen, 1993). Especially multimedia educational applications present a considerable potential as cognitive tools, by showing, proposing and giving direct evidence to the learners allowing them to see, observe, interpret, reflect, seek for direct evidence, and link the acquired experience to prior knowledge through animations, simulations, verbalizations, problem based scenarios, project based learning databases, multiple representations, team-based and collaborative learning (Roblyer, 1996; Hannafin, Hill & Land, 1997; Waern, Dahlqvist & Ramberg, 2000). Thus interactive multimedia technology could serve as a vehicle for constructive learning.

In their manifesto for a constructivist approach to technology use in higher education, David Jonassen, Terry Mayes and Ray McAleese (1993) found that the constructivist roles of technology in education depend on the use of various environments that represent multiple realities, promote case-based learning with real world tasks and environments, and facilitate collaborative knowledge construction. According to the authors, cognitive learning tools are all those that assist learners in representing their own knowledge or alternative representations of the external world, and computer-based applications that can function as cognitive tools including database managers, semantic networking programs, hypertext, spreadsheets, expert systems, and microworlds (Jonassen et al., 1993).

Though Jonassen and collaborators (1993) point out that knowledge construction cannot be achieved with all those computer applications (for example with browsing information systems). The process of knowledge construction would require specific instructional goals of the learning tasks, for which properly developed cognitive schemata have been developed. Those cognitive schemata are scientific ones, only if they have been formed and tested by use of scientific methods and tools.

Another problem arisen is that although too many ideas have been developed and expanded about constructivism and its relation to technology, this learning theory has not yet influenced educational technology systems design and implementation. As Cobb (1999: 15) stated, '*up to now a role for constructivism has been discussed more in principle than in practice, and claims about the kinds of knowledge it produces remain largely untested*'. A number of researchers have been aware of this problem. For example, Kunz (2004) states that learning management systems have considerably delayed the application of constructivist approaches to the delivery of taught knowledge. The author proposes that the next generation of those systems should be based on principles obtained from the main practical educational applications of the constructivist learning approaches (Kunz, 2004), such as: *cognitive apprenticeship* (Collins, Brown, Newmann, 1989), *collaborative knowledge building communities* (Scardamalia & Bereiter, 1994), *goal-based scenarios* or *scenario-based design* (see e.g. Carroll, Rosson, Chin & Koenemann, 1998) to deal with complex real situations, and *constructivist learning environments based on activity theory* (Engestrom, 1987; Engestrom et al., 1999).

In fact, many educational technologies, more or less advanced ones, such as multimedia-hypermedia applications, intelligent tutoring systems, learning management systems, artificial intelligence and adaptive learning systems claim to support teaching and active learning. A problem that exists with those systems is that, despite their considerable potential in education, the majority of them tend to use more traditional pedagogical views and methods. For example, since 1989 the Organization for Cooperation and Development in Education (OCDE, 1989) had pointed out the lack and need for quality multimedia educational software. Nowadays, many software packages have been produced, but their quality may not always be as high as expected.

In an attempt to design educational software packages, which would be accessible through the internet, more recent advanced learning technologies such as Intelligent Tutoring Systems (ITSs) have been developed. But ITSs seem to be more tutor-centered and instructivist than student-centered and constructivist. In order to offer instruction, ITSs develop architectures which are characterized by models of (Akhras, Self, 2002; Stauffer, 1996): a) the domain knowledge which represents the expert knowledge to be learned, organized as a set of correct production rules having a certain structure, b) the learner’s knowledge that represents the correct and incorrect knowledge that the learner has about the domain; each new learner requires an individualized student model; in developing the student model, the type of knowledge (i.e. declarative, procedural) is determined, and c) the teaching knowledge, which represents the teaching strategies used by the ITS to select tutorial activities, present them to the learner and handle the learner’s response.

Moreover, in order to assist students by scaffolding them in learning, these systems often develop a student model based on the learner’s typical knowledge about the domain knowledge (e.g. novice, advanced) or her/his actions within the software (e.g. time on task, number of trials), to subsequently offering guidance towards specific instructional targets. Usually those targets follow traditional approaches leading the learner to the final goal through a series of steps. This final goal is defined in terms of a specific behavior the learner must demonstrate.

This approach does not take into account the individual learner's differences regarding prior knowledge or present motivation. It may be effective for procedural knowledge, which can be exhibited, but is not as effective with declarative knowledge, and higher levels of learning (Stauffer, 1996). Thus, advanced technological platforms for instruction hardly allow room for critical thought, active participation, operational learning and –finally- construction of appropriate scientific knowledge.

On the contrary, constructivist approaches to learning investigate and take into account students’ existing conceptions, ideas, conceptual needs about the knowledge domain, also promoting the students’ active role in learning. Technology-enhanced, student-centered learning environments organize interrelated learning themes into meaningful contexts; they provide interactive, complementary activities that enable individuals to address unique learning interests and needs; they study multiple levels of complexity, and deepen understanding (Hannafin & Land, 1997).

As a consequence, constructivist views may lead to specific architectures of ITSs. For example Akhras and Self (2002) proposed a constructivist architecture of student-centered ITSs and emphasized different values from the traditional ITSs, in terms of knowledge representation, reasoning, and decision-making capabilities of the system. However, the authors illustrate their position by using a rather irrelevant example (making of salad), which has been criticized by other researchers (see e.g. Azevedo, 2002). Azevedo (2002) supported a quite different position that intelligent and adaptive learning environments can be used as meta-cognitive tools to foster self-regulating learning, and thus enhance learning. Young, DePalma and Garrett (2002) also criticized the position of Akhras and Self (2002), and maintained that computers should incorporate factors not only from the individual, but also constraints from the environment in her/his current situation. Despite the different views about the architecture of advanced computer systems, student-centered constructivist learning environments are generally considered as powerful technology–enhanced systems which can act as cognitive tools and foster active learning, critical thinking and higher-order skills (Jonassen, 1993; Duffy & Cunningham, 1996; Hannafin & Land, 1997; Wilson, 1998; Hedberg et al., 2002; Kunz, 2004).

Moreover, a complementary relationship appears to exist between computer technologies and constructivism, the implementation of each one benefiting the other, as the focus of both constructivism and technology are on the creation of new learning environments. A review of the literature on the implementation of computer technology in the classroom revealed that the connection between technology and constructivism lays on considering technological means as cognitive tools, which are able to foster higher order cognitive skills, when they are used by teachers having new roles within technology enhanced environments (Nanjappa & Grant, 2003).

Thus, bringing constructivist principles into the classroom has implications for the learning environment, as well as teachers' and students' roles. The idea of the learning environment fits better with the idea of learning as a process of knowledge or meaning construction, which occurs by the help of multiple and continuous interactions between the person who learns and the means and persons of her/his environment (Perkins, 1998). According to Wilson (1998: 5) a learning environment is *'a place where the learners may work together and support each other as they use a variety of tools and information resources in their guided pursuit of learning goals and problem solving activities'*. The constructivist view of learning emphasizes students' active involvement in the learning activities, collaboration among them and students' interactions with a variety of information resources, in order to construct meaning through experimentation, acquisition of empirical experience and appropriate pedagogical guidance (Edelson, Pea & Gomez, 1998). The innovative use of computers in the classroom leads to important changes of the traditional roles of all the partners involved in the teaching and learning process. Within a new constructivist-collaborative learning environment students are no more patient receivers of knowledge, but active and responsible partners of the construction of their own knowledge, working either in small groups -or individually. Teachers are no more the unique owners and emitters of information and knowledge, but conceivers and designers of students' learning activities, and students' guides and assistants in the learning process.

It is evident that the simple presence of computers in the classroom could not result in such radical changes concerning teachers' and students' roles and teaching methods. Teachers' prior practices and routines influence changes teachers make in their classroom to accommodate technology. In fact, teachers tend to modify the technology to fit their teaching styles rather than modify their teaching style (Miller & Olson, 1994). A possible solution to this situation would be the participation of teachers in appropriate education and training programs aiming at promoting the development of innovative and constructivist teaching strategies with the use of ICT (Sanholtz, Ringstaff & Dwyer, 1996). Such training programs should assist and observe teachers in their own classroom, as we know too little about computer activities in the classroom and we need to understand the reality of ICT use in the educational context (Hinostroza, Rehbein, Mellar & Preston, 2000).

A CONSTRUCTIVIST DESIGN AND EVALUATION APPROACH BASED ON RESEARCH IN STUDENTS' IDEAS

Within the social constructivist framework, research in students' initial ideas, conceptions, conceptual difficulties and needs constitutes an essential dimension which allows the collection of data concerning the students' initial conceptual state and its evolution over time. Research may also allow studying the contribution of specific teaching strategies in students' conceptual change.

We propose a research-based approach for the design, implementation and evaluation of constructivist educational software environments in three stages: research into students' conceptions, and conceptual needs, design of the software, and implementation and evaluation of it. More specifically, the three stages of this approach are the following:

- **Research into students' ideas and analysis of their conceptual needs**

The research in the first stage aims at investigating and studying students' initial empirical conceptions about the knowledge domain under study. Phenomenographic approaches (Marton, 1981, 1986) and methods such as personal interviews, written questionnaires, thinking aloud protocols, drawings tasks, etc. can be used to explore students' existing conceptions and conceptual difficulties and needs at the initial stage of software development. Research with representative sample of students may provide with data useful also in case that the students that are going to use the software are different from the initial sample.

This process differs to some extend from what is already done as 'requirements gathering' phase in current educational software development. As Carroll and collaborators (1998) state, use cases (specify sets of possible event traces but do not describe user experiences and motivations; cooperative design scenarios are used to characterize work flow and breakdowns and "*are used as conversational props in user-developer workshops, but are not cognitively articulated (in terms of user goals, expectations, and reactions) and are not taken as scoping contexts for design rationale*" (Carroll et al., 1998: 1157). In the scenario-based approach to requirements development by Carroll et al. (1998), the 'design team' consists of middle school and high school teachers, human-computer interaction specialists and software technologists. Ethnographic methods are used to collect and analyze data from real classrooms and laboratory activities in order to design and develop scenario-based software relative to a virtual science laboratory. In this approach, students' existing ideas, conceptions, conceptual difficulties and needs are not investigated nor taken into account in the design process, although many important students' alternative conceptions may exist relative to the studied science topics.

Also, this first step of the proposed research-based approach differs significantly from instructional design in that it stresses the exact characteristics of the learners and the learning goals. For example, Liu & Johnson (2003) propose a new approach to design technology systems based on instructional design principles (Reigeluth, 1983/2002; Smith & Ragan, 1993). In this approach an effort is made to integrate and analyze all the factors that may play a significant role in the pedagogical process. This three-dimensional approach includes information, technology and instructional design. Regarding the latter, four major phases are viewed and crucial factors in the first Planning Instruction phase are the analysis of "*content, learners and tasks*" (Liu, Johnson, 2003: 1011). Though, the subsequent described analysis does not make reference to students' prior ideas as a crucial factor to analyzing and decision-making of learning content, tasks, technologies, which are afterwards proposed.

In addition, design methods adopting the activity theory are often focused on factors relative to Human-Computer Interaction (Nardi, 1996) or can investigate the implementation of ICT in real school settings (Romeo & Walker, 2002), without focusing on students' ideas. So the usual design methods do proceed to requirements of teaching, yet without analyzing students' thought and conceptual difficulties.

- **Design**

The second stage of the method includes the design and development of the software on the basis of the results issued from the initial research concerning students' empirical ideas, conceptual difficulties and needs. The analysis of research data may serve as a guide for the selection of both the content to be taught and the learning tasks to be proposed. A step-by-step design of the software aiming to help students change their alternative conceptions and overcome their conceptual difficulties may result in the creation of a constructivist-based electronic tool characterized by a number of features (Jonassen, 1994). More specifically, the software should provide:

- proper content, after analysis of students' conceptions and needs, as a result of didactical transpositions (Chevallard, 1985/92),
- construction of operational content -and context- dependent knowledge,
- multiple linked representations of the complex reality,
- simulations of 'real' situations (Brown, Collins & Duguid, 1989), and authentic tasks in meaningful contexts (Roth, 1995),
- case-based learning, problem-solving situations, thoughtful reflection on experience,
- proper feedback and guidance to confront students' alternative ideas,
- opportunities for collaboration, communication and social negotiation of meaning among learners,
- representations, symbols, language and tasks promoting equity of students of both genders and belonging to various socioeconomic and cultural environments (Solomonidou, 2001/2007).

Sometimes, it is necessary to assign a number of 'aims-obstacles' for the software pedagogical design, especially of science content. The software should provide students with many opportunities to express and evaluate their personal ideas and lead them to 'cognitive conflict' situations, in order to provoke conceptual change and facilitate construction of scientific knowledge. Formative evaluation of the software with a small number of students and teachers may provide elements regarding the ease of its use, and appropriateness of the software's interface, knowledge content and learning process.

This second step of the proposed approach differs from most well known models of designing distance education and e-learning programs, which are oriented to the delivery of rules and processes, do not adopt contemporary educational views and aim at the transmission of knowledge (Pantano-Rokou, 2005).

- **Evaluation and implementation**

A third stage of the approach is finally conducted aiming at the summative evaluation of the software after its use in class conditions and its implementation in real classroom settings. Guiding lines may again be students' ideas, conceptions, eventual conceptual change, and learning with understanding. Also, teachers' opinions about the effectiveness of the software's use in teaching should be included in this stage. Post-test written questionnaires and personal interviews with students and teachers may be used to select data for the evaluation of the learning outcomes, and the software's summative evaluation.

The proposed method seems to be a quite complex task, demanding the collaboration of designers, researchers, and teachers. It would be rare for one single person to integrate all those roles. Therefore, teamwork is necessary between various persons who may have distinct roles in each stage.

- During the first stage of initial research, the researcher has the predominant role assisted by the teacher and the designer in investigating and studying students' empirical conceptions, as well as in analyzing the didactical transformations to define the software's content.
- In the second stage, the designer plays a crucial role in designing the computer environment (i.e. simulations, visualizations, interface) and is assisted by the researcher and the teacher in the design of the pedagogical material to be included in the software (i.e. what kind of activities, tasks, working sheets, questions, feedback, evaluation items,...).
- In the third stage, the teacher takes charge of the pedagogical situation, as s/he organizes the new ICT learning environment to implement the new pedagogical tool. In this stage, the researcher is involved in designing and conducting the research and study students' final conceptions and learning outcomes. The designer focuses on rather technical aspects and aspects regarding the interaction of students with the software they used it. The gathering and study of the research data leads to the summative evaluation of the software.

The novelty of our approach is that all the stages of the usual approach, which has: analysis>design>implementation>evaluation, the students' conceptions, ideas and conceptual needs are the guiding line. Also in our approach, besides the usual persons involved, that is: users/learners, domain experts, designers and programmers, content education researchers are actively involved in investigating and analyzing the students' conceptual state regarding the content of learning in every stage. Thus in the initial research and analysis stage, the design stage and the implementation and evaluation stage not only the usual specialists, but also content education specialists are involved.

Diagram 1 summarizes the research-based approach to the constructivist design, evaluation and implementation of educational software. It outlines the main and assistive roles of the researcher, the designer and the teacher, as well as the main tasks in every stage of research.

Diagram 1. An approach to constructivist design, evaluation and implementation of educational software based on research in students ideas

Stages	**Roles**	**Tasks**
1st : research into students' ideas research into and analysis of students' initial ideas and conceptual needs	**Researcher** **Teacher** **Designer**	Investigation and study of: • students' initial ideas • conceptual difficulties • conceptual needs Analysis of content and assignment aims of the software
2nd : design design, development and formative evaluation of the software	**Designer** **Researcher** **Teacher**	Design of the software's: • content (according to students' existing ideas) • process (simulations, learnung scenarios, tasks, feedback, etc.) • interface Formative evaluation of the software
3rd : evaluation implementation and summative evaluation of the software	**Teacher** **Researcher** **Designer**	• Teaching with the software in class settings. • Research on students' final ideas and conceptual change, as well as of teachers' opinions. • Software summative evaluation after analysis of research data.

EXAMPLES OF CONSTRUCTIVIST EDUCATIONAL SOFTWARE

In order to illustrate the described research approach, two representative examples of constructivist interactive multimedia educational software with science content designed and evaluated in Greece are presented.

1st example: "Interaction between Objects"[1]

The software "Interactions between Objects" aims to support effective teaching and learning regarding Newton's 3rd law and Newtonian Dynamics. The reason to proceed to the creation of this educational package was the significant number and persistence of students' alternative ideas about this science area revealed by a large amount of research studies, and the insufficient emphasis usually science teaching gives in students' ideas regarding Newton's third law (Viennot, 1979). In order to design and evaluate this software an extended research has been conducted involving science education researchers, designers, programmers, students and teachers in the three stages.

The research in the first stage investigated Greek students' initial ideas about the concept of interaction between objects with 10 clinical-type personal interviews (Solomonidou & Kolokotronis, 2001), pre-test questionnaires answered by 451 students, and finally personal interviews with another 26 students of the above sample. The results showed an important divergence (about 70%) between students' empirical ideas and the relevant scientific views and also differentiations concerning students' answers associated with gender, age, school, and area of residence.

The second stage included the design and development of the software on the basis of students' empirical ideas. In order to help students change their initial empirical conceptions into scientific ones, the software simulates real everyday life situations of interaction between objects and models those situations according to the method of extended figures first introduced by Viennot (1979). A powerful feature of the software student is 'run-my-model' processes (Raghavan & Glaser, 1995), as it allows the student to create her/his own model of reality according to her/his ideas and then activate this personal model through an appropriate simulation (in Figure 1 an example is shown). Then the comparison of the student's personal model to the scientific one may eventually lead her/him to conceptual change and construction of scientific views (the software design is described in Kolokotronis & Solomonidou, 2003). The second stage also included a small-scale research for the software's formative evaluation with the help of 8 students and 15 teachers. The students were videotaped while they were working with the software and then participated in personal interviews. The teachers worked with the software and then filled in an evaluation questionnaire. The analysis of the data showed that the software's interface, experiments and tasks were especially attractive to the students, and also contributed to their conceptual change. The teachers evaluated the software as "very good' and made comments regarding aspects of its design, which contributed to its improvement.

In the third stage of research, the software has been implemented in 13 primary and secondary school classes and used in teaching interventions with 226 students. Data have been collected and analyzed in order to perform a summative evaluation of the software. More particularly, the teachers filled in a "diary" in order to report on the attitude and the reactions during teaching of both the whole class and a small group of 2-3 students. Two weeks after teaching, the 226 students answered a post-test written questionnaire similar to the pre-test one. The study of the teachers' reports revealed that the students' attention, active participation and collaboration were significantly more important compared to traditional teaching (Solomonidou & Kolokotronis, 2004). Also, the comparison of the students' answers to the pre- and the post- test questionnaire showed that the percentages of students' incorrect answers had substantially decreased (from 60% to 90%), and that the initial differences associated with gender, age and area of residence have diminished.

Figure 1. "Interactions between Objects": the driver starts moving backward while trying to move his car forward ('run my model')

2nd example: "M.A.TH.I.M.A."[2]

"M.A.TH.I.M.A." is a highly interactive multimedia educational software package aiming to help students construct multiple linked representations and foster conceptual understanding in several science topics (free fall phenomenon in mechanics, geometric optics, heat and temperature, electric circuits, molecules and atoms). The design of the software was based on the study of science education literature concerning students' conceptions and difficulties about the thematic areas developed. For example the literature reviews on students' ideas about the free fall phenomenon (Driver et al., 1994) served to the design of the thematic unit ***'Mechanics'***. In this unit the student can study the free fall phenomenon by running simulations either of natural environments (on the earth's or the moon's surface), or alternative worlds (earth without atmosphere). The falling of an object is studied by tracking the objects' motion, showing a dynamic model of the fall, and dynamic graphs of the evolution in time of vector entities.

The ***'Reflection-refraction'*** unit has been developed on the basis of students' various alternative ideas about light (Driver et al., 1985). This unit simulates a Geometric Optics laboratory where the student is engaged in problem solving activities, such as predicting the result of an experiment related to linear diffusion of light, shadows formation, reflection and refraction, synthesis of color light beams, and observe a highly dynamic and interactive geometric model of the situation under study. S/he can also enjoy a game with little mirrors and diamonds (Solomonidou et al., 2000).

Concerning ***Molecules and Atoms***, an amount of research studies revealed students' alternative conceptions about the particulate nature of matter and their idea of matter as a continuous and static medium (Stavridou, 1995). In order to overcome students' confusion between scientific view of matter's structure and their conception as deriving from everyday experience, the unit ***'Heat and Temperature'*** has been developed in order to promote modelization of appropriate phenomena in the microscopic level. Apart from students' difficulties about the particulate nature of matter, this unit aims at coping with their alternative ideas concerning heat and temperature. The learning environment of this unit simulates a science laboratory, where students are engaged in experiments related to the thermal expansion of solid, liquid or gaseous materials, and to the change of water from solid to liquid and then to gaseous state, and subsequently are introduced to the microscopic models of matter through appropriate modelization tasks (Stavridou, 1995). The student interacts with simulations of several phenomena while the screen may display both a simulation of the relevant experiment in microscopic level and a dynamic graph of the temperature change (Stavridou et al., 2000). Figure 2 shows a screen referring to thermal expansion of a liquid: the left window shows the particles' motion when temperature increases, the central window shows a dynamic graph of the volume change as temperature increases, next the experimental set is shown and on the right there are relevant questions and tasks, aiming to enhance conceptual understanding.

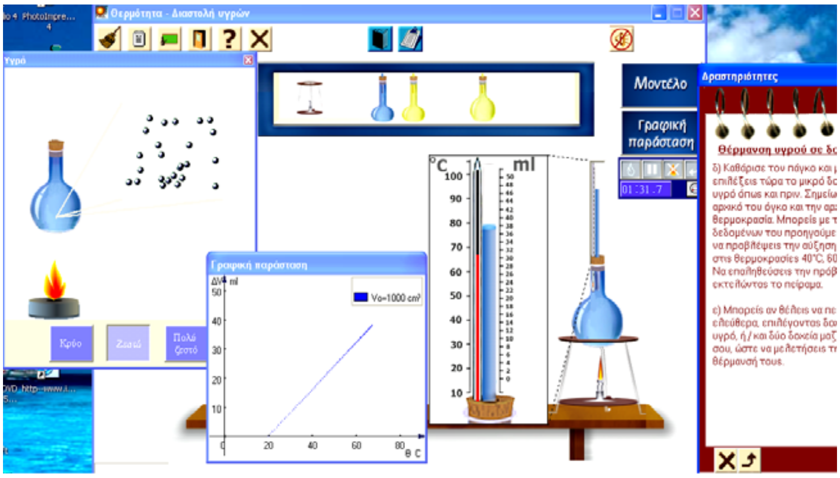

Figure 2: "M.A.TH.I.M.A.": Study of thermal expansion of a liquid

Regarding ***Electricity***, students' alternative conceptions related to electric current (Driver et al., 1985) have been taken into account. The environment here simulates a laboratory providing the students with materials and appliances to allow them get actively involved in experiments in which they manipulate elements and values of entities of electric circuits, and also dynamic simulations of those circuits in microscopic level, in order to help them understand basic electricity concepts (Samarakou et al., 2000).

During the design and development of the software, this was constantly tested in a large Greek secondary school (a science teacher of this school was a member of our design team). The results of the tests during the software's formative evaluation were positive, and the teachers' and students' comments were utilized in order to improve it. After its completion, "M.A.TH.I.M.A." has been presented to teachers during a number of conferences and seminars and implemented in several schools. After its use it has been evaluated with a written questionnaire answered by a number of secondary and primary teachers. Those teachers reported that the software: a) is a highly interactive and user-friendly one with a pleasant interface and simulations of various experiments, b) improves the learning outcomes in every unit it is used, c) contains simulations which promote conceptual understanding, d) "it constitutes a very good learning tool", and e) helped both the teachers to save time in experimentation, and the students to improve their attitude toward science, as well as to assure their active involvement in teaching.

Conclusion

The paper proposes a constructivist approach to the design, implementation and evaluation of multimedia educational software. Central to this constructivist approach is the idea that students' existing ideas and conceptions play a crucial role in learning. Many advanced computer-learning systems do not take this assumption into account, and tend to use more traditional pedagogical views of knowledge transmission. The need for the creation of constructivist computer systems has been discussed, as well as the importance of a constructivist-collaborative learning environment to foster students' conceptual understanding (Wilson, 1998; Perkins, 1998). Due to their specific interactive features computers are considered as powerful mind tools or cognitive tools (Papert, 1980; Jonassen, 1993; Duffy, Cunningham, 1996), which can promote operational and active learning, and they can implement constructivist strategies that would be difficult to accomplish in other media (Driscoll, 1994).

In order to illustrate the proposed research method, two examples of Greek educational multimedia software with science content were briefly presented, and more specifically, "Interactions between Objects" aiming at to promoting construction of scientific knowledge in the area of Newton's 3rd law and Newtonian Dynamics, and "M.A.TH.I.M.A.", aiming at helping students construct multiple linked representations and conceptual understanding in several physics areas.

But a problem that exists is that attempts like the ones described in this paper tend to remain restricted to their local context with few chances for broader dissemination. As Kunz (2004) pointed out, many of the advanced systems are commercially available, while others are in-house products developed mainly by groups of researchers, more often working at universities or other institutions. The former are well known, accessible and usable via the Internet, whereas the latter are not well known to the large public. Educational software packages inspired by constructivist views have not been widely spread distributed. The position of this paper is that constructivist theory and research into students' ideas and conceptual evolution should inform on more extensive scale both the design of educational software packages and their implementation in schools and evaluation. In addition, the presented approach proposes a broader collaboration of several specialists coming from different science areas, in order to improve the teaching process and learning outcomes. An important perspective of this work would be the appropriate –technical- design which would permit constructivist educational software packages to be introduced in the web, in order to serve as useful distance and open learning tools for a larger number of students, teachers, practitioners and researchers.

NOTES

1. The software "Interactions between Objects" has been designed by the author in collaboration with Dr D. Kolokotronis, developed at the Educational Technologies and Software Design Laboratory

(University of Thessaly, Greece), and evaluated by Dr Kolokotronis during his doctoral thesis elaboration at the University of Thessaly (1999-2002).

2. The software 'M.A.TH.I.M.A.' was designed and developed by a group of researchers coordinated by Associate Professor M. Grigoriadou (University of Athens). The project was financed (1998-1999) by the Greek Ministry of Education (project "Reformulation and Innovation of the Curricula in Science through Production of Instructional Material" - EPEAEK, E22), and supported by the Pedagogical Institute.

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