An Agent-based Collaborative Learning System

Adina Magda Florea

"Politehnica" University of Bucharest,
E-mail: adina@cs.pub.ro
http://turing.cs.pub.ro/~adina

Extended version of the paper "An agent-based collaboration learning system", A. Florea, published in Proceedings of ICCE99, The 7th International Conference on Computers in Education, Chiba, Japonia, 4-7 November 1999, p.161-164.

Abstract

The paper presents a collaborative on-line learning system for open and distance learning that tries to respond to the requirements of an efficient and motivating learning process. The system comprises several learning modes that try to combine the traditional style of teaching with "problem-based" learning: learning by being told, problem-centred demonstrations, problem analysis, and assessment of acquired knowledge. A fifth mode, creative problem solving, as an essential part of the learner-centred approach, will be supported by future versions of the system. Cooperative learning is achieved either between the student and the tutor or inside a group of learners interacting or not with the human tutor. Student interactions with the system may be either synchronous or asynchronous. The system is a CSCW environment enhanced with artificial agents that represent an active part in the learning process. It includes personal agents to assist the students and the human tutor, an artificial tutor that tries to partially replace the human one during student interactions with the system, and an information agent to search relevant information.

Keywords: **Computer Supported Collaborative Learning, Agent Architecture, Pedagogical Agent**

Introduction

The development of the New Information Technologies not only bring ever more ambitious and complex challenges in everyday life and work, but also provide means and tools to meet such challenges. Nowadays, the current state of the art changes so fast in most fields of human activity that the professional qualification is no longer a lifetime acquisition. Just periodically up-dating knowledge and skills acquired during the years of professional training is no longer good enough. Ever larger socio-professional groups have to adopt the drastic solution of re-orienting themselves towards completely different, newly emerging domains. To develop and maintain the aptitude of the labour force in such a competitive and ever changing environment, efficient computer based teaching/learning systems have to be developed to complement or to substitute traditional teaching in different forms of education. Efficiency, scientific and pedagogical quality, affordability and user-friendliness are the basic requirements of such systems.

To increase the efficiency of learning and to commit the student, the new educational paradigm of "learner-centred", "participative learning", and "problem-based" learning has began to show its merits. The goal is active exploration, construction, and active learning rather than the passive attendance of lectures or textbooks reading [NS96]. The NIT offers the premises and means to develop educational systems based on such a paradigm. In the same time, as in any other human activity, collaboration in knowledge acquisition is an important dimension of the learning process. Communication through computer networks, be they Internet or Intranets, permit the learners to collaborate with others in solving problems, to explore new means of communication and information access, and to develop group reasoning skills.

The paper presents a collaborative on-line system for open and distance learning that steamed from the requirements of an efficient and motivating learning process. The first section of the paper summarises the current views of learning and teaching that have shaped the pedagogical strategies and the design of the system. The next section describes the basic functionality of the system and how different learning and instructional modalities are achieved. Next, the presentation is geared on how the artificial agents in the system actively support the learner, relieve the learner of routine tasks in the learning process, and try to partially replace the human tutor. The paper ends by discussing some elements of the system interface that support collaboration and related work.

Current Perspective on Learning and Teaching

Knowledge that is accessed or transmitted but never put to use during learning may be difficult to remember or use properly afterwards, in real-life situations. In the same time, people learn best when motivated by a certain task or challenge, or when they need knowledge and skills to solve a problem at hand. Most of the current teaching is focused on the content of the curriculum, structured around basic topics of a discipline. Although this is and will definitively remain an essential aspect of teaching, the learner-centred approach must necessarily complement the current way of teaching. We are thus witnessing to a shift from the paradigm of "the sage on the stage" to the one of "the guide on the side", in which the learning process is centered towards the learner and his/her active participation in the learning process. The idea of participative learning is supported by the construstivism approach, a fundamental viewpoint about the nature of knowledge acquisition. Constructivism is a set of beliefs about knowing and learning that emphasises the active role of learners in constructing their own knowledge [Res87, Gla89]. The construction of knowledge is viewed to be the result of a learner's attempts to use his/her existing knowledge to make sense of new experiences. This entails both the modification of concepts and the reorganisation of knowledge structures. Although teaching can facilitate the construction of knowledge, it is not the direct consequence of a simple knowledge transmission process.

Despite an important number of computer-based learning tools, open environments for learning and on-line learning materials, the pedagogical approach followed by most of these tools is still much influenced by the traditional style of teaching, namely knowledge and information transmission. Participative and cooperative learning has been only recently considered as an important asset in computer-based learning, creating thus the premises of shifting to the "problem-based" and cooperative paradigms in computer-based learning.

On the other side, computer-based learning and ODL need to provide tutorial support to students, typically in the form of a human who can answer questions, provide help and guidence. This limits the number of people who can participate simultaneously in ODL training as it is difficult to supply human assistance in a timely manner to remote users in different time zones. Assisting, complementing, and partially replacing the human tutor by automatic tools in such environments seems to be the answer to this problem, but artificial intelligent tuturs are difficult to develop. There is still a long way to go before achieving the "human" dimension of "computerised" education and training. Considering the important progresses of artificial intelligence which have brought the basic research in the field to everyday life and real-world applications, the lack of "intelligence" of the computer-based learning tools currently available is really surprising. It is our aim to develop a computer supported system that will combine the traditional teaching approach with the "problem-based" and "learner-centred" paradigm of learning and to gradually introduce in the system artificial intelligent components that will add the "human-like" lacking dimension to the computerised learning process. Because the system is open and distributed, artificial intelligent agents seem to be a promising solution in achieving the proposed goal.

Functionality of the Collaborative Learning System

This section presents the basic functionality of a collaborative on-line learning system for open and distance learning that steamed from the requirements of an efficient and motivating learning process presented above. The learning system is a CSCW (Computer-Supported Cooperative Work) environment in which group interactions may take place in the same location or in geographically dispersed locations, at the same time (synchronous mode) or at different times (asynchronous mode). In the system, cooperative learning is achieved either between the student and the tutor/expert or inside a group of learners interacting or not with the human tutor. The system comprises an artificial tutor (the Tutor Agent) that tries to partially replace the human one during the student interactions with the system.

The system comprises several learning modalities that try to combine the traditional style of teaching with the "problem-based" and "learner-centred" style. To support the perspective on learning and teaching presented before, we have identified the following learning modalities: learning by being told, problem-centred demonstrations, problem analysis, assessment of acquired knowledge, and creative problem-solving.

The **learning by being told** modality corresponds to presentation of "classical" on-line materials, such as course notes or slide-show, but augmented with selective inspection of the materials depending on student answers to different questions and exercises. The **problem-centred demonstration** level implies the demonstration of how one particular problem is solved by the tutor, be it human or artificial. This refers to either setting up the parameters of a pre-existing program, running the program and visualising the results or executing a plan to achieve the goals of a given problem.

The **problem analysis** modality corresponds to the analysis of a solution proposed either by the tutor or by a student. This involves critiquing the undertaken decisions and explaining the rationale behind these decisions.

The **assessment of acquired knowledge** level implies both self-assessment and assessment of the student performances, either automatically or by the system-assisted human tutor. We consider the self-assessment level as one of the learning modalities of the system as feedback on the acquired knowledge enhances the learner's motivational beliefs.

The **creative problem solving** modality implies the student being in control and solving the problem, individually, in cooperation with the tutor (artificial or human), and/or in cooperation with other students in the system. By creative problem solving we mean two levels of learning behaviour: learning by solving problems and learning by discovering new ways to solve a problem or new explanations to a problem solution. For the time being, the system supports only the first four modalities but provisions were made to integrate the creative problem solving modality in the future.

In the **learning by being told** modality, which corresponds to the "traditional' style of lecturing, on-line interactions and feed-back are provided to enhance the pedagogical value of the environment based on CSCW characteristics. The presented material is organised along several conceptual paths: the content path, which can be explored at compulsory, optional, or advanced presentation level of the material, and the concept path in which the student is following the presentation and use of a concept throughout the entire learning material. Roadmaps are associated to each of the conceptual paths the student may follow, to facilitate the process of knowledge organisation and concept formation. When following the content path, the student is presented with some questions or simple exercises, at the end of each chapter or section, to test his/her progress in understanding the presented knowledge. According to the quality of the answers, the student is advised to go again through parts of the material. This first level steams from the work in [Flo99a, Flo99b].

The second modality implies the **demonstration** of how one particular problem is solved. The demonstration may be performed by the tutor, by a student, or by a group of students that may or may be not assisted by the tutor. The demonstration may refer to setting up the parameters of a program, running the program and visualising the results, or to executing a plan to achieve the goals of a given problem. This level corresponds thus to taking a pre-existing solution for a given type of problem, tuning the solution by specifying particular parameters or features for the particular problem instance, applying the solution to solve the problem, and visualising the results. Result visualisation may be followed by the interpretation of results. The students may collaboratively participate in setting up the initial parameters of the problem solving paradigm and interpreting the results. The human or artificial tutor may also collaborate/help the students in selecting the appropriate values. Shared visualisation of initial parameter settings and of the obtained results facilitates collaboration in learning. The interpretation of results is mainly performed through the chat-like facility of the system by communication among students, with the synchronous or asynchronous presence of the human teacher. The artificial tutor may also give limited interpretation, depending on the particular problem. The demonstration experiment can be recorded in the system to be later used by other learners in asynchronous mode interaction. In asynchronous mode, a learner may either try and perform his own demonstration or, alternatively, may investigate previous demonstrations performed in the system either by the tutor, or by the peer learners.

As stated before, the **problem analysis** modality corresponds to the analysis of a solution proposed either by the tutor or by a student. For the time being, the proposed solutions may be selected from an existing repertoire of generic problem solutions that may be tailored according to the tutor or student options. In fact, this third level comprises problem centred demonstration followed by the collaborative analysis and explanation of the proposed solution and obtained results. The problem to be analysed is presented to the students in terms of: problem specification, the main steps that lead to the problem solution, the selected input values for the problem parameters, the obtained results, a set of possible underlying principles that might have been used for solving the problem, and a set of possible concepts that might be useful for understanding the problem solution. The students have to select, among the possible choices, the principle/principles that were used in solving the problem and the most relevant concepts that support the problem solving process. The human or artificial tutor may be addressed in case of uncertainty by the hint or explanation facilities of this learning modality.

The analysis of solution steps and of the correlation between selected input values and obtained results is carried out by direct communication through the chat-like facility in which several users, including the tutor, contributes with their opinions and critiques to the analysis. In order to support the analysis, the tutor or learners in the system may invoke a search facility (the Information Agent) to perform search of relevant information either on the learning material available in the system or on the Web. The tutor has the possibility to select relevant parts of the collaborative problem analysis and record them in the system, along with the corresponding demonstration, so as to enable other learners to investigate the results at a later time. The selections of principles and concepts performed by the students may also be recorded in the system, to be used either for collaborative learning in asynchronous mode or for student performance assessment.

For the time being, we have concentrated on two particular subjects to be developed in the framework of the collaborative learning system: sorting algorithms and resolution theorem proving [Llo84]. We use the second subject to be more precise in specifying the problem analysis modality. For a given set of clauses, the problem specification implies the presentation of the problem in natural language, the formalisation of the problem in first order predicate logic (FOPL) and the equivalent set of clauses that resulted from the transformation of the FOPL form. The input parameters to be collaboratively set are: the inference rule/rules to be used in demonstration, including answering, the resolution strategy, the top clause for linear strategy or the set of support for the set of support strategy, the maximum number of generated resolvents or maximum depth of the proof tree. The obtained results refer to the clause that finally generated the empty clause, the number of generated clauses, the number of clauses that were kept after elimination, the number of unification attempts, the depth of the proof tree, the obtained answers if any. The steps that lead to the problem solution are synthesised by the proof tree. The underlying principles that are presented to the student to choose from comprise several levels of detail, namely principles that refers to general theorem proving methods, to particular resolution strategies indicated by corresponding definitions, to correlation between particular strategies and types of clauses in the problem instance. Among the concepts to be selected are inference rule, strategy, completeness, consistency, termination conditions, decidability, etc. Several details on how these different learning modalities are supported by intelligent agents will be given in the next section.

The forth modality corresponds to the **assessment** of student acquired knowledge. The exercises have different levels of difficulty and are indexed accordingly, both for the student and in the system. The answers to the exercises are: select a choice among several possible answers, match answers to multiple questions, input a text formed of predefined words in a table, input a formula (which will trigger lexical and syntactic analysis). The assessment part may be entered either in practice mode (self-evaluation) or in evaluation mode. When entering the practice mode, the student has available on the screen follow-up links to relevant parts of the learning material available in the system to help him in selecting the correct answer. In the same time, the student has the possibility to retrieve instances of problem-centred demonstrations and problem analysis, to further guide him in selecting the answer. The system records the number of correct or incorrect answers and computes the total number of points, which corresponds to the student evaluation. The assessment part is also based on the work in [Flo99a, Flo99b]. For the time being, the assessment of acquired knowledge is conceived to be performed only at the individual level of the student, but we foresee to extend the conception and design of this forth modality such as to support collaboration in evaluation and collective evaluation of the performance level of a group of students.

Agents to Support the Learning Task

The architecture of the system is a multi-agent one, human and artificial agents collaborating together to achieve the learning task. There are several agents in the system, as depicted in Figure 1. A learner in the environment is endowed with his own digital personal agent. A dedicated window can be activated when the user wants to interact with his personal agent (*PerA*) but the *PerA* may react and make the learner aware of its presence when relevant information has to be communicated. The *PerA* is responsible for monitoring the user's actions, for creating the learner's profile and preference profile, for providing data to the management component to create the learner's history (to be detailed in the sequel), and for entering in dialogue with the *PerA*s of other learners.

The Personal Agents are also responsible for retrieving pre-existing solution for a given type of problem and managing communication and interactions while the user in engaged in the problem-centred or problem analysis modalities of learning. They can be instructed to save learning experiences, such as particular parameters setting and associated results. The tutor in the learning system has also his personal agent, which is similar to the other *PerAs*, but without the function of creating the learner's profile or history. This uniformity in treating the personal agents facilitates communication and coordination in the system. The user is communicating with his personal agent by means of a menu-driven approach, while the *PerA* is displaying information and comments in natural language. We are currently considering adding a voice facility to the *PerA* to make the learner or teacher aware of important events in the system even if he/she is concentrating on a particular task.

A second agent in the system is the artificial tutor, namely the Tutor Agent (*TutA*). The *TutA* is capable of assisting the students and partially replacing the teacher. While in the first modality, when the student is answering to questions and exercises associated to the in-line course material, the Tutor Agent may suggest what parts or relevant topics of the course the student has to revise, depending on given answers but also considering the learner's history. The *TutA* can also assist students in the system during the application of the second and third modality of teaching, namely problem demonstration and problem analysis. It can participate to the initial settings of the problem parameters, it can contribute (partially) to the interpretation of results, and it can give hints or explanations about what principles or concepts are most relevant to the problem at hand. These activities are also correlated to the learning profile of the student. For example, when making suggestions about how to set initial parameters, the Tutor Agent will advice the student more or less, depending on the learner's profile developed until the time being.

For a given category of problems, the *TutA* has an internal symbolic representation of the problem solution, causal links that connect problem characteristics and possible categories of input values to concepts and principles used in the problem, and standard (limited) explanations to be selected for a certain class of results. For example, considering again the resolution theorem proving subject, the TutA may have the standard explanation that the SLD resolution [Llo84] is not adequate to be used to prove a particular set of clauses because they are not Horn-like. The predefined categories of problems, with associated representations for solutions, causal links, concepts and principles, are stored in a knowledge base that can be accessed both by the human users and by the Tutor Agent. The Tutor Agent is mainly built-in but it has also limited capabilities of learning from the human tutor how to contribute to the problem parameter settings by applying a variation of the ID3 algorithm [Qui86, FM96]. Several more sophisticated machine learning algorithms and deep representation of the problem solution will be included to increase the competence and efficiency of the artificial tutor.

The artificial tutor may be activated on demand, either by a student of by the teacher. The interaction between the Tutor Agent and the learners has the advantage of always being in synchronous mode. The interface between the learner and the *TutA* is realised also by the *PerA* of the learner. The *PerA* is responsible for calling the *TutA* to be active part of the learning process, and thus to assist the student. In the same time, the *TutA* will query the *PerA* of a learner on the student profile, so as to tailor its advice according to the abilities of the learner.

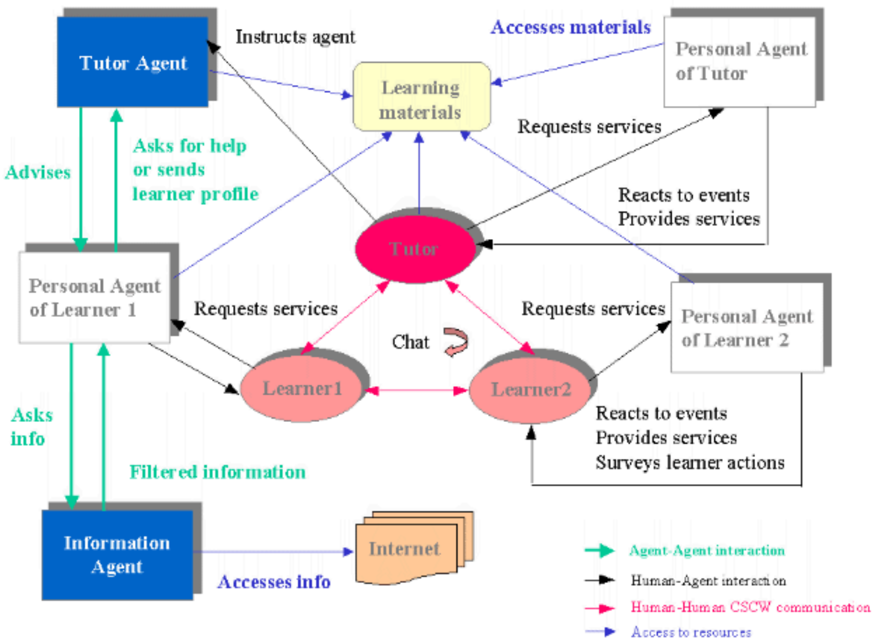

Figure 1. Agent-based collaborative learning in the system

A third agent in the system is the information agent (*InfoA*) which is responsible of retrieving and filtering information from specified sources that can range from the learning materials and experiences available in the system to the entire Web. The filtering criteria may be specified by the learner when calling the *InfoA*, may be retrieved from the preference profile of the user (provided by the user's *PerA*) or may be created as a combination of the two (by user we mean either a student or the human tutor). Extra details on how the *InfoA* and the user preference profile are developed are outside the scope of this paper.

The learner's history refers to several aspects of previous student-system interactions and comprises the learning profile of a student (which is different from the preference profile). The learner's history includes the numbers, dates, and modes (synchronous or asynchronous) of the student sessions with the system, the level of achievement in self-evaluation and evaluation mode, the selected modalities of learning during each session, peer learners in the group while engaged in collaborative learning, and how often the learner asked for assistance to the artificial tutor. The learning profile of a student is a qualitative synthesis of some of these quantitative elements, including, for the time being, the level of achievement of the student, namely beginner, intermediate of advanced, preferences for individual or group learning, preferences for the learning modalities in the system, and level of requested assistance.

We are considering extending the learner profile with several other qualitative features and we are currently working on a model of a group profile in learning. This group profile will be used to correlate the activity of the Tutor Agent with the level of knowledge of the group. As the group profile will be accessible to the the human tutor, he may, in this way, get a better understanding of the group with which he/she is working. A further development of the system will be dedicated to conceive and build an intelligent agent to assist students in creative problem solving by collaboratively participating to the synthesis of the problem solution.

The system includes a management component which is responsible for managing the system users, for example assigning login names and passwords, and two databases existing in the system, namely: the learner's history database and the database with the recorded learning experiences. A third database contains the learning profile of the students, but this database is accessed by the personal agents of each user and by the Tutor Agent.

System Interface

The system interface comprises several learning and communication areas to support both individual and collaborative interactions (Figure 2). There are two types of areas in the user-system interface: one type is represented by private areas that are to be viewed and managed only by the individual user connected to the system, while the other is the common type interface which corresponds to areas that are shared by all users connected in the system in synchronous mode or where an individual user can visualise previous collaborative experiences. For example, the Private Work Area may be used by the student for private work, private notes, etc.; the Private Learning Area may be used for browsing course notes or for assessment. The Common Area for Parameter Settings is used to collaboratively tune a solution for a specific problem instance, the Common Chat Area for informal discussions among members of the group, and the Common Area for Analysis (also chat-like but with possibilities to be recorded in the system) to collectively analyse problem solutions. A Coordination Area is used for showing and managing group interaction in the system, namely: who is participating, who is inputting data of a form or another, who is in control of the interaction at a given moment.

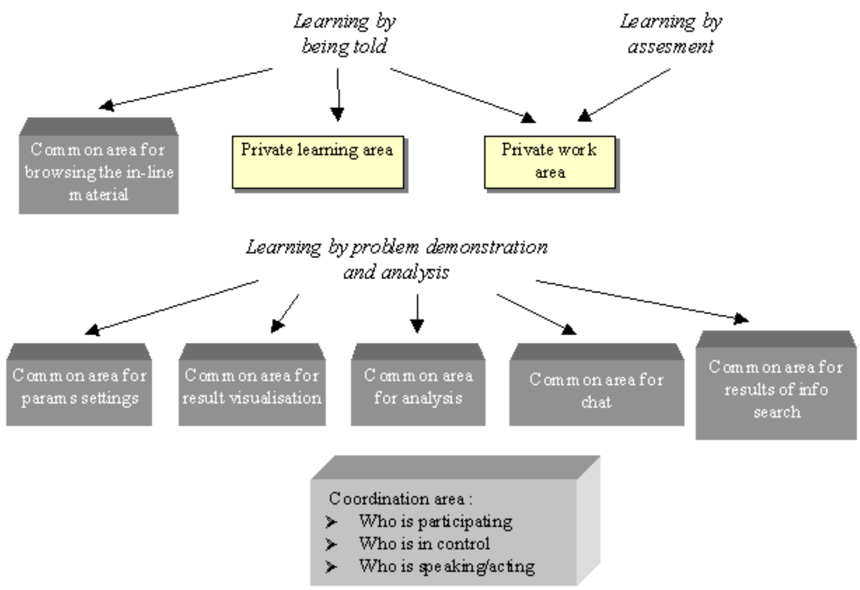

Figure 2. Components of the system interface and their relationship to the learning modalities

Related Work

The professor is conducting a class on how to solve a problem collaboratively. It uses a part of the screen, seen by all students, to formulate the problem and the stages necessary to follow for finding the solution. In each stage, students are required to enter facts, ideas, learning issues, and tasks in the shared area of the screen. The teacher critiques each stage of the work then make assignments to teams of students from the identified issues. A possible overview of a snapshot of such a session is presented in Figure 2, which shares some elements with the Collaboratoty Notebook product

The Multiple Case-based Approach to Generative Environments for Learning (McBagel) of Georgia Institute of Technology in Atlanta is an environment for synchronous collaboration where students gather for brainstorming and planning activity and where a problem gets understood and broken into solvable pieces (Gruzdial et. al., 1996). McBagel is based on the problem-solving learning method and is used with success in medical and business schools. Also from Georgia Tech is the Collaborative and Multimedia Learning Environment (CaMILLE) which supports asynchronous collaboration: students share resources found or invented while working separately. The environment is used in mechanical design classes.

The Digital Agora project, developed at Acadia University in Canada, provides a Web-based training system that facilitates the collaborative analysis of complex problems, such as peace initiatives, bioethics questions, consensus negotiation, and environmental issues. The Digital Agora (Watters, Conley, and Alexander, 1998) allows users to access the huge amount of information available on the Web in these areas, organize it, and work collaboratively to understand and resolve problems concerning these complex issues. The project supports Web-based hypertext design with authorship of nodes and links, discussion groups, collaborative analysis and writing, simulations, graphical representations of complex issues using lateral maps, quizzes and evaluation.

The Royal Center for Learning and Academic Technologies that serves Penn Sate's 12-campus Commonwealth College plus four additional undergraduate campuses, has developed Project Vision, a learning environment for creating courses which integrates technology skill development and use with content learning, requiring local and distributed team project work, and building cooperative learning skills (Deden, 1998). In the beginning, students take a first Vision course that teaches them how to use and evaluate Internet tools and resources in research, abilities to communicate in a computer environment, and requirements of Web-based presentations. They can afterwards be enrolled in one of several subject-oriented Vision courses that requires them to design case studies and work in a team, including multidisciplinary teams. For example, students in computer science are paired with philosophy students to produce multimedia interpretations of the levels of hell in Dante's Inferno.

The PuppetMaster which provides a high-level interpretation and assesment of the students based on a model from reactive planning research, namely the situation space. PuppetMaster is a pedagogical agent used in virtual world simulation for training of military tank crews.

Models of Online Courses which discusses characteristics of new learning environments, including the pedagogical evolution of on-line course materials, and issues in teaching and learning online.

In [WM98] is an interesting presentation of a methodology for approaching the problem of migrating a course from the classroom to the Web, including four main learning modes : passive presentation, high-level interactive demonstrations, student led practical exercices and reference to written source notes. The discussion is illustrated on the MPI On-line Web based distance learning course developed at EPCC.

Conclusions

We have presented a distributed on-line learning system for collaborative learning based on artificial agents. The system supports synchronous and asynchronous cooperation among learners, cooperation being achieved either between the student and the tutor/expert or inside a group of learners interacting or not with the tutor. The underlying learning paradigm is based on a combination of the traditional teaching approach with the "problem-centred" and "participative" one. The system comprises a set of facilities to assist the learner at several levels of the knowledge acquisition process: learning by being told, problem-centred demonstration, problem analysis, and assessment of acquired knowledge. A fifth learning modality in the system, namely the creative problem solving, is envisaged as a future development.

The supporting technology is CSCW enhanced with the emerging paradigm of intelligent human-computer interaction. The architecture of the system is a multi-agent one, human and artificial agents collaborating together to achieve the learning task. Among the agents in the system, the Tutor Agent tries to partially replace the human teacher to synchronously assist the students in the learning endeavour at the time of their convenience.

The distributed solution has the advantage of creating an ODL environment to be joined by any interested learner. The system is an effective response to the increased demand for cooperation and learning in today's open environments, both academic and economic, and to the necessity of developing effective learning tools that can be smoothly integrated in the professional development process but also with company work.

The presented learning system is part of a collaborative effort to develop a novel intelligent virtual environment for learning. The system is under development at "Politehnica" University of Bucharest.

References

[Flo94] Florea,A. The Automated Theorem Proving (ATP) module of Portable AI Lab. The Summer School on "Computed Assisted Instruction in Artificial Intelligence". Organised by the Romanian Academy and the Dalle Mole Foundation of Researches on Artificial Intelligence, Bucharest, 1-5 August, 1994.

[Flo99a] Florea, A. e. a. "Représentation logique des connaissances pour les agent intelligents", Grant AUPELF-UREF No. 11018/99, in the framework of the "Université Virtuelle Francophone" Programme, 1999. http://sunsite.pub.ro/uvf

[Flo99b] Florea, A. Le professeur virtuel: fiction ou réalité? In Proc. of "Forum Initiatives 99 – Colloque Universités virtuelles, vers un enseignement égalitaire", Edmundston , 27-29 August, 1999 (to appear).

[FM96] Florea, A. and A. Moldovan. An Intelligent E-mail Agent. In Proceedings of ROSE'96, the 4th Romanian Conference on Open Systems, 30 October -2 November, 1996, Bucuresti, pp .91-99.

[Gla89] von Glasersfeld, E.. Cognition, Construction of Knowledge, and Teaching. Synthese, Vol. 80, 1989, pp.121-140.

[Llo84] Lloyd, J.W. Foundations of Logic Programming. Springer Verlag, 1984.

[NS96] Norman, D. A. and J. D. Spohrer. Learner-centered education. Communications of the ACM, Vol. 39, No. 4, 1996, p.24-27.

[Qui86] J.R. Quinlan. Introduction of decision trees. Machine Learning, Vol.1, No.1, 1986, pp.81-106.

[Res87] Resnick, L.B.. Education and learning to think. Washington, DC: National, Academy Press, 1987.