# A Collaborative Environment for Semi-Structured Medical Problem Based Learning

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## Abstract

Problem Based Learning (PBL) and Cooperative Learning are both supported in a rich environment for active group learning. Groups of students are given a medical exploration environment to support learning by discovery and exploration. The environment implements a current approach to problem based learning (PBL) and extends it to support the joint reasoning and cooperation aspects in medical teams. An information system approach for a complete cooperative PBL environment, called Computer Assisted Learning and Exploration (CALE), is based upon these concepts. CALE acts as a multi-media repository for case materials and manages the structured group access to those documents and user generated information. CALE supports collaborative learning, exploration of facilitator editable medical simulated patient cases, and access to reference materials. With the case presentation shell being the same for all cases, new cases can easily be added.

**Keywords:** Problem Based Learning, Collaborative Learning, Exploration and Discovery Systems, Case and Knowledge Acquisition, Case Display, User Annotations, Group Support Systems, Group Tutoring Systems, Shared Information Spaces, CSCL Shells.

## 1. Introduction

Computers are increasingly being used in education. Often they are used to teach computer concepts per se or tutoring programs are run to teach individual students about facts in a certain domain. A number of educational software packages exist, which are often developed as specialized course-ware, that is very cost- and time-intensive to produce. Rarely do we see computers used to support a general learning approach and thus allow a generalized approach to the production of course-ware.

The area of learning in a group, working together on a problem, rather than learning facts, has received considerably less attention than the above mentioned applications. The concept of socio-cognitive processes in learning [6, 8] can add a rich dimension to the quality of information systems in the learning process. The need to provide high quality group settings in education that allow to learn domain and social skills is growing. Teachers are challenged to give adequate support in group learning situations.

The objective of this paper is to show that information systems can support a wide pedagogical spectrum of group learning. In particular, problem based learning (PBL) and cooperative learning are examined as good candidates for educational theories for which generic system support can be provided. A second objective is to show that the generation of course-ware for such a generic system can be done quickly and simply if a clear underlying model is chosen.

Section 2 introduces the general concept of problem based learning while section 3 identifies ways in which information systems can aid PBL. Section 4 examines cooperative learning and establishes a connection to PBL. Section 5 presents the design and implementation of CALE, a rich environment for active group learning. The underlying case structure and the design of new cases is described in section 6, while section 7 describes a student session with the system. Evaluations are reported in section 8.

## 2. Problem Based Learning: A Candidate for CSCL

Problem based learning (PBL) differs from traditional approaches to learning in that PBL centers around a problem that is presented in a context. In medical education this context is provided by documents and views, simulating a patient. Rather than learning facts by rote, students have to apply their knowledge to work on defining hypotheses about the patient's problems, supporting those hypotheses with observation, facts, and background knowledge, and eventually generating solution approaches. Facts and knowledge are thus put into context and can be turned into medical skills [11]. In a medical school PBL environment, the students typically collaborate on a case in groups of eight to twelve. Guidance in the problem based learning process is provided by medical teachers who act as

learning facilitators. The facilitators help student groups stay on track, provoke lateral thinking, aid in overcoming mental blocks or dead-ends, and prevent students from pursuing improbable avenues too far [9].

Though PBL has been generally successful, the formation of student PBL groups in medicine has mostly been a matter of scarce resources, rather than a desired design parameter. Sufficient materials (X-rays, CT-scans, etc.) were not available to allow all students to work on the cases individually. Since the involvement of facilitators is extremely important, it is another constraint on the group size. Yet physicians in hospitals or private practices rarely work in an isolated manner. Doctors co-operate with other doctors, they rely on support personnel, and they interact within large organizations, such as hospitals or HMOs. By acknowledging these facts, we can turn group learning into an opportunity for learning joint reasoning skills and practicing cooperation in a medical context.

PBL has conventionally been supported by paper documents or "paper patient simulations" [2]. Recently electronic information technology has been embraced to aid in PBL (e.g., DxR, Harvard [1]). Systems have been proposed to tackle various problems posed by the PBL process, such as document handling or visualization. There are many multi-media systems that had some success at presenting a "high-fidelity" patient simulation [5]. Therefore, group size is no longer dictated by the scarcity of resources. On the contrary, information systems can directly support and foster the learning of joint cognitive skills and of social medical cooperation. Other types of systems to support learning and tutoring have been suggested. In particular intelligent tutoring systems [7, 4]. These systems will not be reviewed in detail here because they need a large knowledge base rather than focussing on tool and group aspects. In addition the focus of this paper is on learning rather than on tutoring. PBL can now be put to active use in the articulation and definition aspects of cooperative learning [10].

## 3. Using Information Systems for Improving PBL

One of the largest problems with current paper based PBL is its lack of cooperation support for student groups. Groups are formed because of limitations on resources. If enough facilitators and materials were available, groups would eventually consist of only a single student. This view neglects the potential of joint cognitive and learning processes as well as the actual requirements of working in medical teams rather than as a singular practitioner. With the arrival of information systems to support PBL, that argument no longer counts. Cooperative learning must be acknowledged as a goal in itself and thus actively supported.

Student generated materials are an important factor in problem based learning. While working on the case, students group their ideas, observations, and questions into categories: facts, hypotheses, and "need more information". Documenting these important indicators of progress for the next session becomes a problem in a conventional classroom setting. Records may differ, copies have to be made, and cross-references can not be established easily. Worse than that, the observations that were made about a certain document, say a blood-smear, are recorded separately from that smear. References to blots on the smear must be recreated in the next session. Cross-referencing support and the ability to pull local and coordinated central information generated by students together with the supporting original documents becomes a major need for the advance of PBL.

The use of electronic information systems can facilitate group communications, and can record the communication as the group works through the case. Annotations can be made directly on the x-rays, blood smears, etc. when a student observes a certain fact or comes up with a new hypothesis. To integrate this scattered, student-generated information, a central notebook could provide hyper-media links to the local notes and case and reference materials. Thus students would create a joint information space that records their individual and joint explorations. Asynchronous work is supported by leaving pointers, hints, and findings for group members who can build on previous discoveries.

For evaluation purposes and to give feedback to the group, the system can maintain a log of the materials accessed. Date, time, and user-id stamps can allow the evaluating facilitator to see the blind alleys tried, the integration of results by individual, or the time used by the group to finish. This record need not be a static report. Facilitators can use a play-back facility to see a time condensed development of the groups reasoning process and how it unfolded starting with the initial problem presentation, unfolding through group action.

The above review of PBL has identified PBL as a powerful method for learning skills. Yet the lack of explicit acknowledgement of group processes in the learning of skills became appearant. The next section address this lack.

## 4. Supporting Cooperative Group Processes

Reviewing the research literature concerning the most effective methods of teaching, one finds that success depends on the learning objective, the individual student, the teacher, and the content [8]. Juggling these factors is almost an unconquerable demand even for a master teacher; it is even more so for an information system which attempts to model each of them. The next best method can be seen in students teaching other students [8]. This observation leads us to cooperative learning. Cooperative learning is a structured form of collaborative learning.

Thus it provides a theoretical framework and an item plan for support through an information system. Hassard [6] describes the benefits of cooperative learning as follows (page viii):

> Educational practitioners such as David and Roger Johnson, Robert Slavin, and Spencer Kagan reported that cooperative learning resulted in high academic achievements; provided a vehicle for students to learn from one another; gave educators an alternative to the individual, competitive model; and was successful in improving relationships in multiethnic classrooms.

To allow more teachers to use this vehicle for more students, information systems can incorporate and enhance many of the principles of cooperative learning mentioned in the quote. Among the leading principles of cooperative learning that can be supported are:

- Cooperation: Heterogeneous small student groups work toward a common goal via positive interdependence and individual accountability.

- Active Learning: Structured assignments create discussions that lead to active learning.

- Prompt Feedback: Feedback from peers and facilitators is received immediately, continuously, and to the point.

- High Self-Expectation: Self-esteem is enhanced through an emphasis on peer tutoring and the respect for diverse results, resulting in higher expectations for ones own achievements.

- Respect for Diversity: Different learning styles are accommodated by peer teaching in the group from their own special and particular perspectives, particularly enhancing liking and respect among students from different racial or ethnic backgrounds.

## 5. CALE: An Environment for Cooperative Problem Based Learning

Based on the requirements outlined in the last two sections, an experimental information system to support cooperative problem based learning (C-PBL) in medical teams was designed, implemented, tested, and anecdotally evaluated. The system specifically supports improved data administration, group dynamics, group communication, and cooperative learning. The resulting implementation, called Computer Assisted Learning and Exploration Environment (CALE), is in operation[1] at the University of Pittsburgh School of Medicine for the "Integrated Case

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[1] Starting April 1994.

Studies and Medical Decision Making" course[2]. The system was designed to be flexible enough to support changes and paradigmatic advances in the C-PBL curriculum as it is further developed. The approach taken by CALE gives each individual student the freedom to explore and discover, while tying their individual efforts into a coordinated group learning process with a clear overall goal structure.

CALE provides students with a very rich and not overly structured medical exploration ground. The core of this discovery ground is specified by case designers, using a notation that allows concise description of salient medical facts and relationships the students are expected to discover in working through a case. Helpful probes and questions are specified that can keep the students on track so that the learning environment can be challenging without being frustrating. In addition, the case designers have feedback on how the case is actually used, so that the case can be improved for its next use. In these cases certain roles are created. One may think of the case as a network of documents that is collectively unveiled by the students, with certain parts of the network necessary to unveil other parts. Yet these parts may only be accessible to students carrying the necessary role. Thus CALE is promoting positive interdependence.

One of the goals of our system was that the students should not always need to leave the C-PBL session environment to explore reference materials and find answers to their questions. There are many resources currently online that the students can access, and many others could also be made available through the system.

The CALE system is both a "learning tool" and a "teaching tool". As such, its users fall into three categories: students, facilitators, and case designers. The goal is to link basic science aspects of medicine to the clinical environment. The students are presented with a case and can use the clinical documents that are available to analyze it.

The facilitators evaluate the work of groups by having access to the notes students have written and answers to questions, along with a chronological listing of the decisions a group has made as it works its way through a case. In addition, the facilitators assign individual students to groups and indicate the session levels which the group is allowed to explore.

Case designers create the simulated patient case by defining the exploration environment. They can attach materials to a case and specify the conditions that a group must meet in order to gain access to those materials. The goal of the design was to enable the case designers to specify a complex environment for the C-PBL session
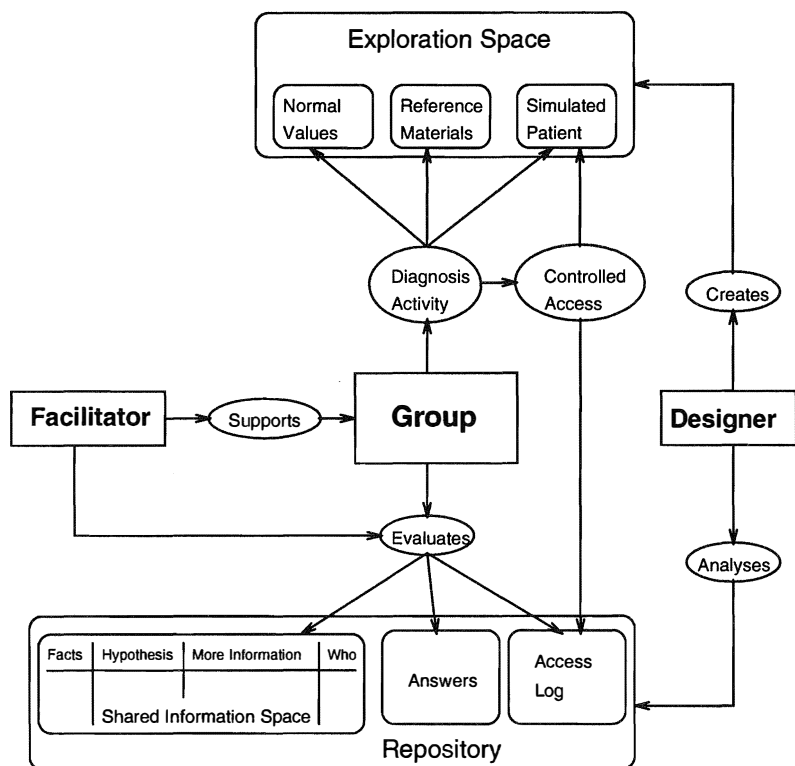
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Figure 1: Major Modules of the CALE System

through the use of simple rules.

CALE is designed as an event driven system with a graphical user interface. The interface presents the user with icons, labels, and buttons representing possible choices. The system can be used with a minimum of training. There are no deep menu trees or commands that must be remembered. The flexibility of an event driven interface requires that the program handle any appropriate input at any time. In addition, the "event loop" that allows input must be programmed in such a way that the system responds quickly enough so that the user finds it responsive.

A multi-user database is used to store the structure of the case as well as a record of the individual's or group's exploration of the case such as access attempts, answers to questions, and notes. This allows several students in the same group to work on the same case on different workstations, as well as allowing students to work at different times, and have access to the group's communication. By storing the structure of the case in the database, the cases can be easily modified to emphasize different goals for exploring a case. When each material has a cost or a time attached, groups can evaluate themselves based upon these criteria, as well as on the patient outcome.

CALE is partitioned into several individual architectural modules which perform specific functions. There are three principal modules: the student interface, the facilitator interface, and the case designer interface (figure 1).

The students can access case materials, reference materials and shared and individual note taking tools from their principal control panel. This control panel is dynamic according to which categories are appropriate to the current case. Text boxes are used by students to take notes, as well as to answer questions. The central blackboard acts as the coordination center for the students. This gives structure to the discussion and allows individual students to tie observations made in an asynchronous session to the overall learning effort. CALE allows hyperlinks from the document where the observation was made to the central blackboard [13]. Thus local information and central coordination are achieved. The blackboard follows the PBL example of dividing information into three separate classes:"Observed Facts","Hypothesis", and "Need More Information". The implementation of discussion support and structuring systems has been explored in a number of systems, such as gIBIS [3]. It has never before been applied though to medical education and cooperation. We also added another category to help the students coordinate themselves. Each entry on the blackboard, primarily those in the "need more information" category, could be turned into an action item, which in turn would be assigned to a team member with a due date. CALE keeps track of these commitments and thus allows students to structure the learning task.

In addition to the note taking ability, during the course of an interactive session a student may be prompted

by the CALE system to answer a particular question attached to a material or rule. The student can respond to the question within a text window provided by CALE. Each response is saved as part of the note/text repository as textual information.

The case designer has control of the case material repository and specifies access control for the case materials. The case material repository is made up of digitized documents, including x-rays, patient charts, slides, EKG strip charts. These materials are stored with accompanying information such as date and type of medical data. The repository also contains any reference materials that are relevant to one or more cases, such as portions of textbooks, journal articles and bibliographies.

The basic function of the access control module is to provide the necessary control to allow or deny access by the student to certain case materials. When a student requests access to a case material, CALE locates the record in the materials table corresponding to the item selected. CALE then scans the request table to see if this material has been previously requested by the group or student and appends a new record to the request table noting the request for access. Then CALE checks the "question-material" table to see if the designer has entered any questions that must be posed to the student. The user is prompted with the text of the question(s) and a text editor is displayed on the screen in which the student types their answer. Finally, CALE checks for any other access constraints placed on the material item by the designer (if the material item has not yet been seen).

# 6. Case Design for Problem Based Learning using the CALE system.

It became apparent in the early case design work for CALE that a concise but powerful notation for specifying access restrictions and precedence was needed. Natural language and structured description techniques are quite limited in their usefulness because it is hard to keep track of all of the alternatives and possible states which may arise during the exploration of a case. In addition, it is difficult for the designer to have a sense of the overall environment that he or she is creating.

We found that many case designers think intuitively in terms of flowcharts. This approach graps the idea of semi-structured exploration of a document space rather ill. Because of the complexity of the possible solutions to a problem, facilitators think of one "via regia". The vast number of permutations that can be created by designing paths through the document space lead case designers using flowcharts to overly linear structures. If at a certain point students can either visit document 1 and then document 2, or they could equally well visit document 2 and then document 1, case designers need to use two paths to show this. The number of boxes in the flowchart keeps growing because necessarily documents appear on more

than one path. Another problem with this approach is that the designers must cope with the "state explosion" by designing very linear exploration spaces, with an overly limited number of possible "solution paths". In extreme cases designers create one linear path with a small number of short cul-de-sacs branching off.

To alleviate this problem, we developed a graphic notation (figure /refnsf1) that allows case designer to specify constraints on the access to materials in a case. This notation clearly shows how open or restrictive the access is, and allows the designer to envision the complete exploration space. All solution paths are implicitly contained in this graphical notation which simply shows constraints between documents and document sets.

# 7. A Session with CALE

To provide an insight to the student interface, let us look at a team tackling a case. It is the first session for a new case. All of the nine students in this team are assembled, and huddle around CALE. As they log on in group mode they decide to first check the patients history. Figure 3 shows the screen entities the student group sees after this first menu selection. The patient history is shown in the window in the lower left hand corner, it consists of a video-clip of the patient and the following text: The patient under study is a 4 1/2 year old white male that has been refusing to walk for a considerable amount of time.

The control panel is located in the upper left corner. Several choices are available to the student at all times. These choices allow them to access reference materials and the blackboard, and to use a toggle switch to change between user and group mode. The rest of the choices displayed are dependent on what is available for the current simulated patient. Those are choices such as laboratory values, imaging, patient history and physical examination findings. The size of the control panel is dynamic and it can display as many or few of these patient specific categories as are appropriate.

On the right hand side of figure 3 is the notepad for local observation that relate to the patient history just seen and heard. The top half of this window allows the students to enter their observations, while the lower half contains a read only display of all of the previous notes that this student or other group members have made. In figure 3 the student has entered a comment on the notepad.

One of the students in the group suggests to follow the hypothesis that the patient is suffering cerebral problems. This is recorded under the hypothesis category in the blackboard. One of the case specific categories, "Laboratory tests" has been chosen to follow up on this hypothesis. A dynamic choice list has been displayed, listing all of the possible choices under that category. From this list a material, "CT-scan of the head" was selected triggering a question that the student must answer: "Have all necessary tests been performed?".
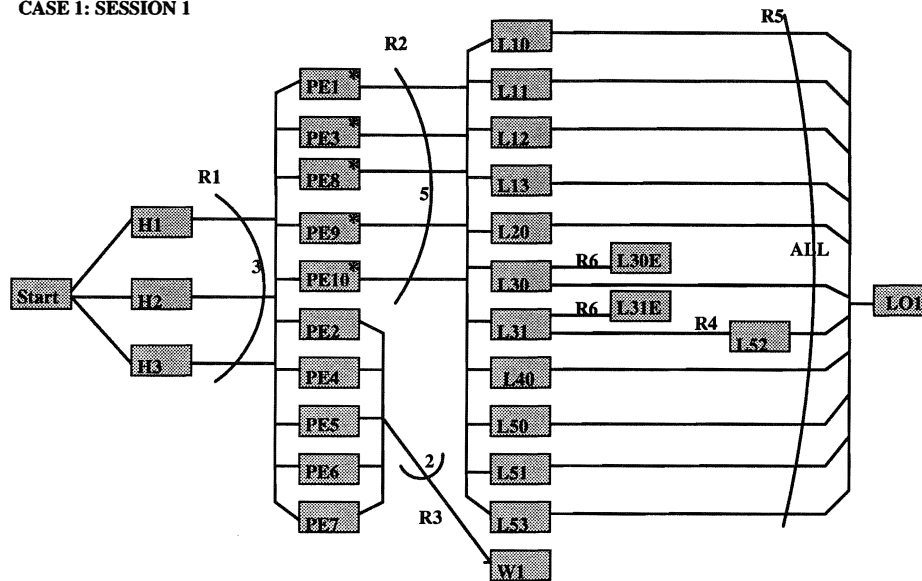
Figure 2: Case Design Graph.

A question can be linked to one or more materials, but questions are usually developed and assigned specifically to a single material. Another sample question might be: "Do you know of any third party payor who will pay for laboratory tests on a patient who was not examined?" [12] The answer to questions can later be reviewed by the group during the evaluation phase, and by the facilitator when assessing how the group did and how they can improve.

Our group answers the question just to see the message display. The hypothesis and the test are not related. Our group now starts to take a more structured approach. A number of hypothesis are generated. Each results into a number of additional information requests. These requests are recorded, like in a chauffeured meeting sessions, and student names are put behind the requests, to identify responsibilities. Thus our group has developed a first task plan. We now leave our group and come back a day later when one of team members returns to work individually in user mode.

Our student reviews the blackboard to see which information she needs to find to rule out certain hypothesis. She decides that the CT-scan should now be permissible because in the last session the group has conducted a number of test that usually precede a CT-scan. This reasoning shows to be correct and the CT-scan is presented. The student enters her observations into the margin note that pops up with the image. She thus leaves information for her team members and works on her own assignment. Her entry is linked to the central blackboard.

As she is scrutinizing the CT-scans once more, another student logs in at a branch campus. This student can only come once a week to the central university. His tasks depend on the normalcy of the CT-scan, as now cerebral problems are ruled out for the moment. Via a talk facil-

ity the two students establish contact (a later version of CALE will allow videoconferencing). They discuss their latest findings and the consequences for the probabilities of hypothesis. After this the local student logs off, while the student at the remote campus keeps working on the problem. Tomorrow the group will come back together to meet with their facilitator and review their approach to this case.

## 8. Evaluation and Future Research

CALE has been evaluated with two classes of medical students (ca. 160 students each) and their facilitators at the University of Pittsburgh. CALE had been introduced to the *Medical Decision Making* course. This course represents the transition from the basic science to the clinical part of the curriculum. For each group of ten students there was one facilitator and one reserved PBL room with an X-terminal that was connected to a central DEC Alpha running CALE. There were 16 such groups/rooms each semester. Each group worked on a total of thirteen cases in the course of the two months. Some cases thus ran for a week, other cases lasted less than a week.

During the two month duration of the course we closely followed the groups. In addition the students kept sending their impressions and observations about the system to the evaluators via email. A special *suggestions* button was incorporated into the system for this purpose. During the use of the system students could thus report immediately their subjective observations and impressions of the system. The second source of data collection was an elaborative debriefing session after the course with students and facilitators. This session was semi-structured
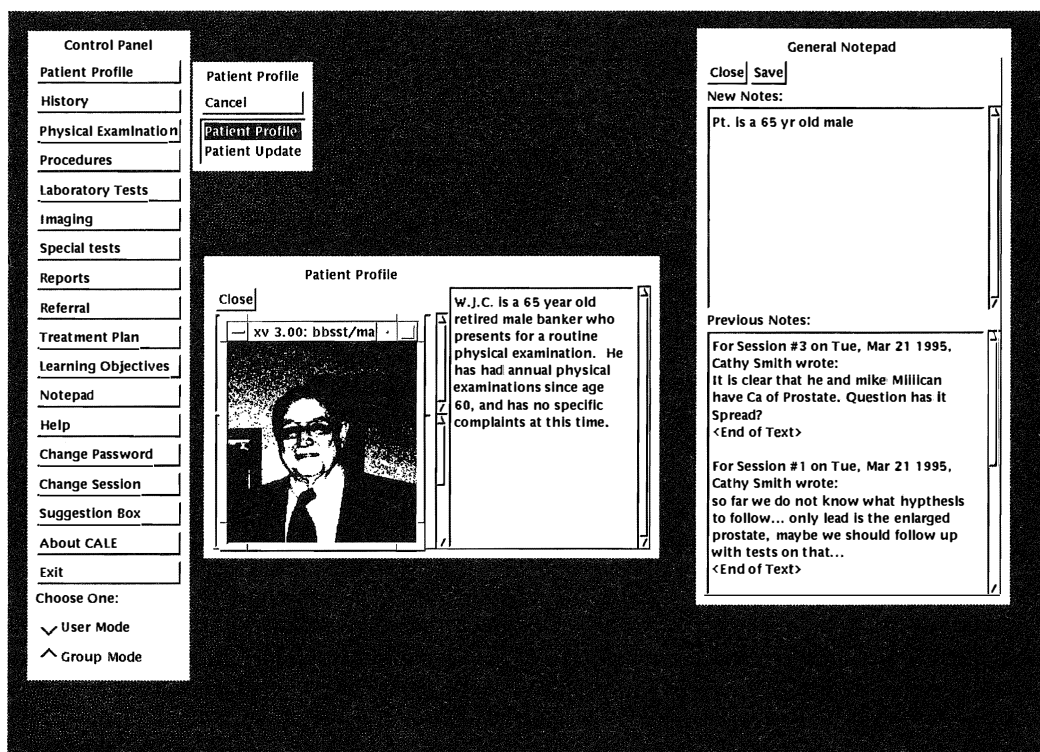
Figure 3: Opening Screen

following a topic and question list to assess subjective impressions.

Our major finding was that students enjoyed manipulating the CALE user interface and were generally excited by the opportunities offered by the system. Menus and other tools were immediately understood and used correctly. Students would try a number of solution approaches to the problem given by CALE until the system aided them in narrowing the hypothesis space. Students commented on the appropriateness of this aid. Experienced facilitators observed the students using the system and commented on the qualitative improvements over the paper based implementation.

Students noted that some of the cases were overly linear. This linearity was embodied in the number of documents that were not accessible upon request. Students commented that this repeated rejection was frustrating. During the discussion of this problem in some of the cases we discovered that the problem was not inherent in the CALE-approach but had to do with the experience of the case authors. CALE allows to build a very open and exciting environment. Yet authors do not immediately realize the potential of the system and follow the simpler linear

approach of cases where one and only one action must follow the other. That of course means that most documents are not available to the students. Upon identifying this problem and working with case authors the quality of cases could be greatly improved by increasing the average branching factor in the case graph.

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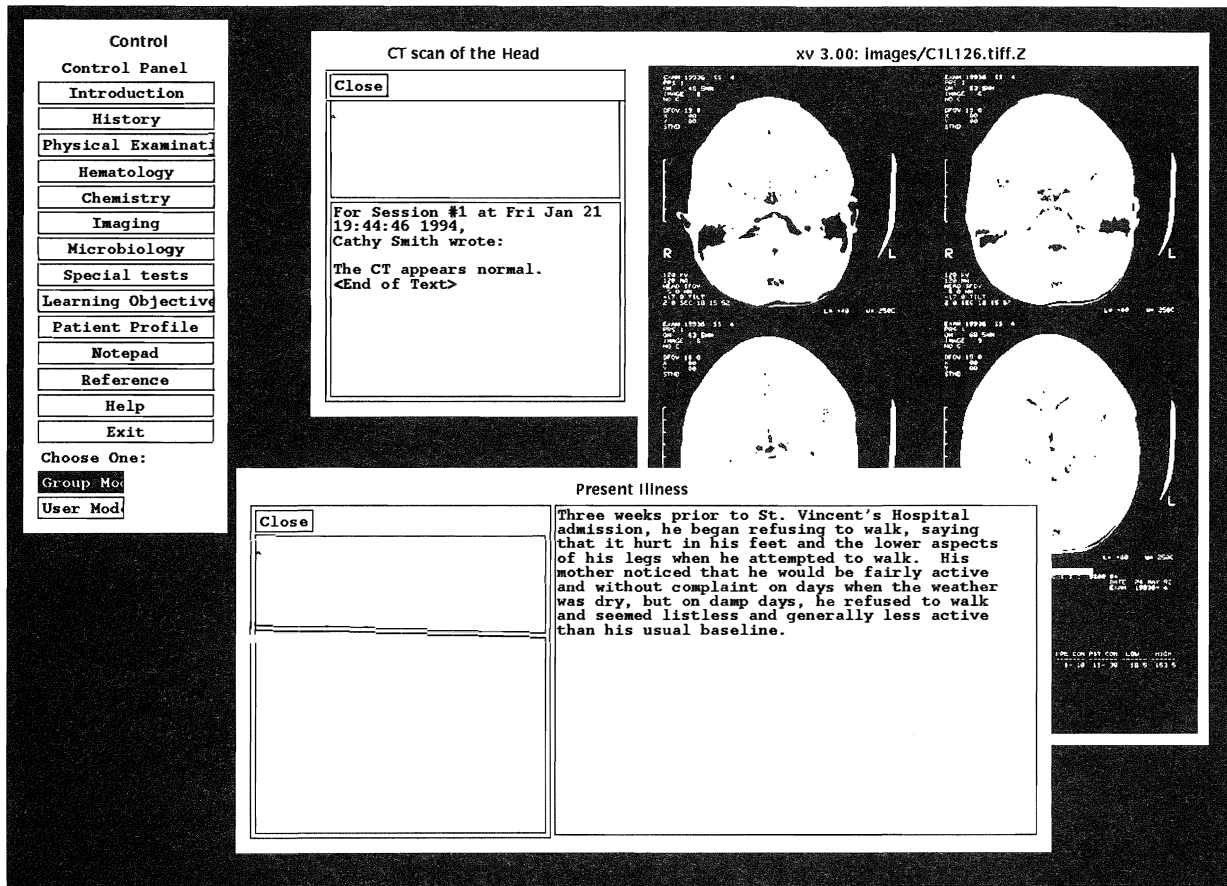
Figure 4: Sample screen from student interface

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