A computer simulation designed for problem-based learning*

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Objectives As problem-based learning is increasingly used in medical education, there is a growing need to capture the diversity of the events occurring during problem-based learning sessions in order to understand the way in which students learn. The computer simulation described attempts to analyse *a posteriori* how students reason and learn during such sessions.

Design A computer simulation was designed to perform a detailed analysis of the following features: pattern of information searched, formulation of working hypothesis and identification of learning issues. The program, which has been running successfully for 2 years, was developed using local resources and accepts any clinical problem, provided it is written in a suitable text file format. The program has been applied in the discipline of pathophysiology.

Setting Faculty of Medical Sciences of Lisbon, Portugal.

Subjects Medical students.

Results An example is presented of how prints were analysed in order to evaluate the 'progression profile' of the students, and a comparison is made with other similar instruments.

Conclusions The program improved understanding of the relationships between the inquiry strategy and hypothesis formulation and also of how self-learning (triggered by learning issues) influenced further analysis of the cases.

Keywords *Computer simulation; education, medical; educational measurement; problem-based learning.

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Introduction

This work describes the development and application of a clinical computer simulation designed according to the problem-based learning (PBL) methodology described by Barrows[1], which provides a detailed record of all the steps followed during the process in an attempt to analyse *a posteriori* how students reason and learn throughout the sessions.

The widespread use of PBL in medical schools around the world[2-5] has been accompanied by a large number of research studies on PBL processes and outcomes. Broadly, two main areas of research on PBL can be identified: (1) comparison with conventional curricula regarding acquired knowledge, diagnostic reasoning skills, motivation and attitudes towards learning[6-8] and (2) the evaluation of students' satisfaction with and perspectives on learning using the method[9,10]. Growing concern about the measurable outcomes of PBL was expressed in a recent paper[11], in which some possible methods of improving PBL were suggested, such as the organization of internationally accepted curricula and psychometrically validated methods of evaluation, the fostering of attitudes among students and tutors to facilitate cooperative PBL teamwork and the teaching of group process diagnostic skills.

However, most of these points concern the outcomes of the method and not the processes that mediate and moderate its relationships with the learning process. This may be partly due to the extreme diversity of the learning environments created during the PBL sessions, which cannot easily be captured by the tutor or even by an observer. In order to overcome this difficulty some groups have analysed written records or videotapes of the session[11-13]. Recently, a new methodology has been developed in an attempt to obtain a temporal record of the events 'that mark the group's reasoning'[13], observable in a video registration of the PBL sessions.

On the other hand, although clinical computer simulations are widely used in PBL settings, they are yet to be fully accepted as a research tool for examining

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specific aspects of the learning process at any of the stages of medical education – from pre–clinical to postgraduate. However, application of the new information technologies to teaching and to evaluation of students[14,15] can provide useful 'experimental' research models. Advantages are that the same teaching material can be presented to the students, assuring uniformity of criteria used to access the information, each working group or individual can evolve their own strategy of moving through a case, there is no emotional reaction of the computer to incorrect responses, and the records of the students' work can be easily recovered and analysed[16,17]. Finally, computer-based learning materials create, in general, stimulating learning environments[18], provide clear educational objectives and promote effective use of information technology[19].

The purpose of this article is to describe the steps involved in the development of a computer-based learning simulation based on the traditional PBL module (PBLM)[20], illustrating how it was applied in the discipline of pathophysiology and how it can be used to analyse the learning strategies employed by the students in a PBL context.

Materials and methods

Development of the PBLS

The main objective of pathophysiology teaching is to improve the students' understanding of the mechanism of disease as a physiological dysfunction of the various systems of the body at a stage at which they have very little contact with patients[21]. In this context it was considered relevant to introduce the PBL methodology with the following objectives: to motivate learning, to structure knowledge in a clinical context and to develop self-learning skills. We have recently reported our experience[22] using the paper simulations, PBLMs, produced by the Department of Medical Education of Southern Illinois University School of Medicine[20].

The development of the problem-based learning system (PBLS) began in 1992, involving a team composed of experts in pathophysiology, who identified and translated the PBLMs and designed the core framework of the simulation, a computer programmer and a specialist in medical education. The computer programmer wrote the program, designed the screen layout and produced the scanned images that were included, while the educationalist designed questionnaires to evaluate the students' satisfaction with the PBLS and collaborated in the tutor training programmes.

The PBLS was first evaluated by the members of the Department, in 1993, and a few corrections were made to improve the structure of the program. During the academic year of 1994–95, all the students of pathophysiology used the program in two sessions as an introduction to the PBL methodology. This initial experience allowed the detection of errors and the formulation of suggestions, which enhanced and simplified the program interface with the users. The PBLS was used for the first time by all the students in the academic year of 1995–96.

During this preparatory period we also developed written support materials to help the students during the tutorials: a manual for the PBLS and a guide to the PBLS sessions. Thirty-six clinical problems were also translated into Portuguese and are now available in the PBLS format, covering the specific objectives of the discipline.

General structure

The program (PBLS) was designed in the Visual Basic compiler and runs in Windows 3·11 or Windows 95. The PBLS is an 'open' program, since it allows the conversion and the updating of any clinical problem, provided it is written in a suitable text file format, and the inclusion of digitized images. Each problem needs less than 1 Mb of hard disk space, if no images are included. Linked to this program is another (GEST), which allows the selection of the problems to be used and access, step by step, to the reports on the work performed by the students.

The PBLS starts with general information about its content and specific instructions about how to use the program.

As in the PBLM from which it is derived, the PBLS provides all the clinical information about a patient organized in a predetermined sequence and divided into six phases: phase 1 – patient encounter (usually with very little information about the patient's problem), which can be accompanied by a digitized picture of the patient; phase 2 – present illness; phase 3 – review of body systems; phase 4 – personal, familiar and social background; phase 5 – physical examination; phase 6 – laboratory findings and other diagnostic procedures. The initial information is all that is volunteered by the PBLS. All the other elements can only be obtained by choosing one question at a time from predefined lists ranked in alphabetic order, similar to the ones used in the PBLM, also included in the program. The PBLS also demands a working hypothesis explaining the clinical findings in terms of the underlying pathophysiological mechanisms at predetermined stages. Furthermore, it also asks, at the end of each phase, what were the learning issues raised during the

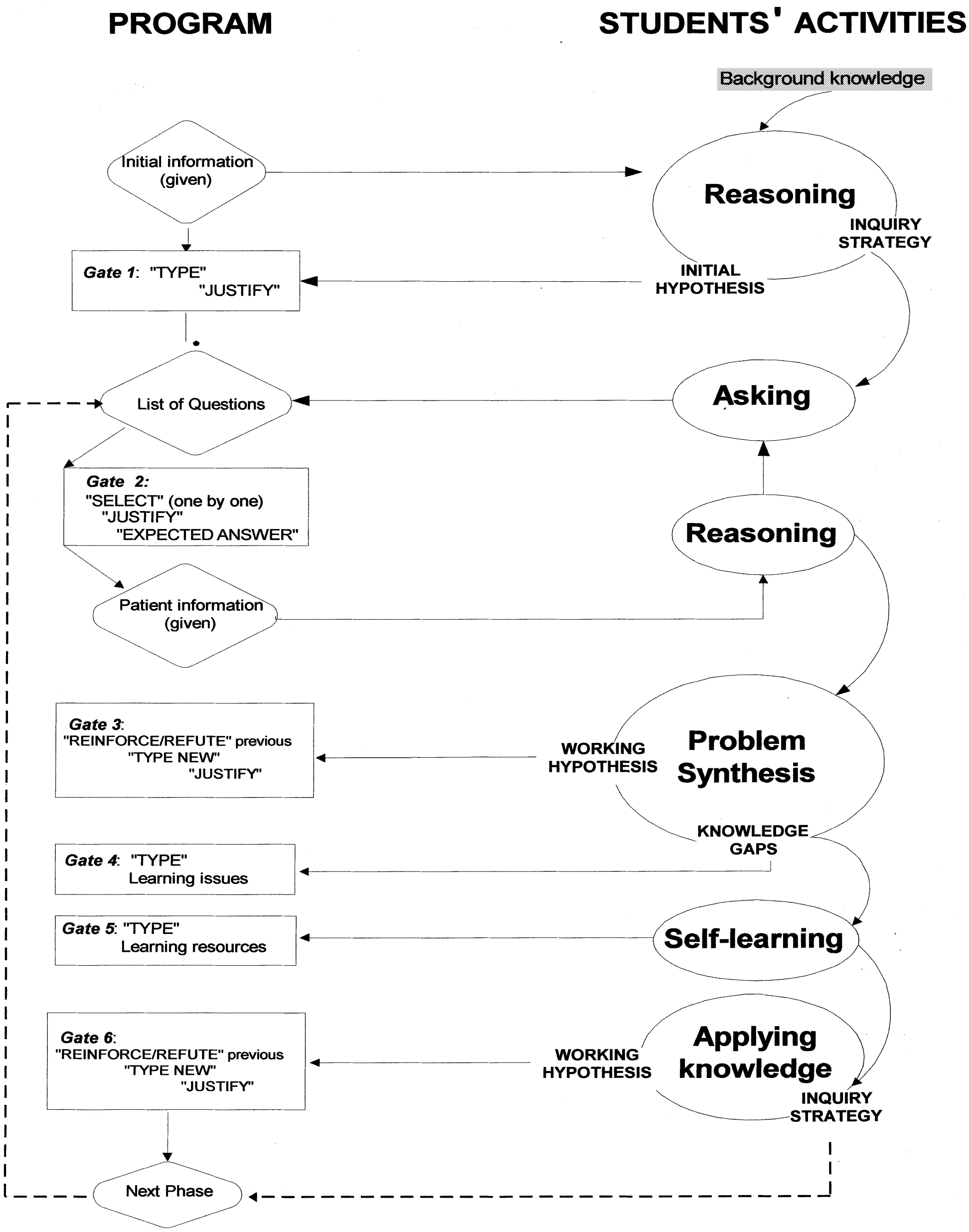

Figure 1 Relationship between the steps of the PBLS and PBL skills. ◇ information given by the PBLS; □ 'gates' (students' tasks); ○ PBL skills.

analysis of the case and the learning resources to be used.

Access to the clinical information provided by the PBLS in a textual format is 'gated' after each question by the introduction of free text in spaces, where the program 'asks' in sequence for justification of the question and the expected answer. It is only afterwards that specific clinical information is given (Fig. 1). For each phase the students can ask all the questions available which cover the clinical information about the patient.

The transition between the different phases of the problem is also 'gated' by the introduction, in similar spaces, of the working hypothesis, learning issues and learning resources (Fig. 1).

After reading the initial information, the first 'gate' (Fig. 1) appears when the students select 'Next Phase' in a button placed in the lower part of the screen

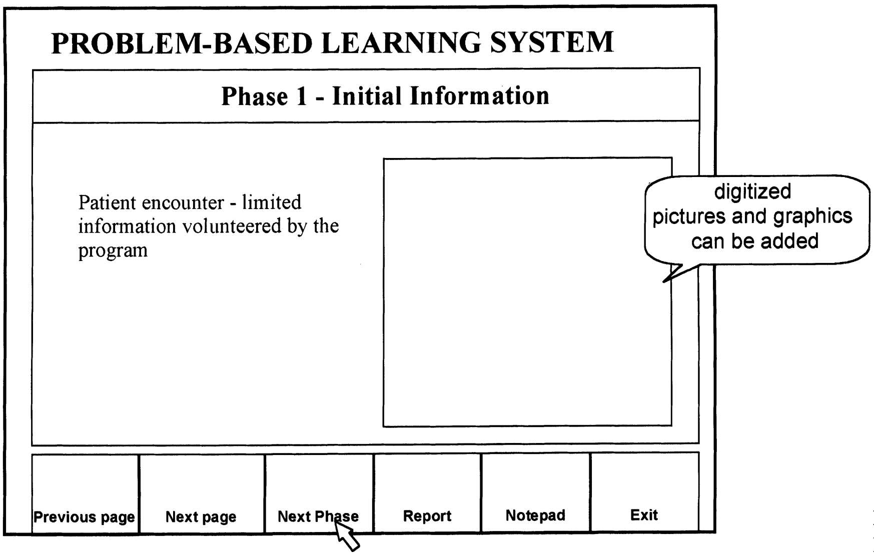

Figure 2 Example of the layout of the PBLS.

(Fig. 2), by clicking the mouse. At that stage a 'window' appears on the screen asking the students to type the initial working hypothesis. For each hypothesis introduced, the program asks for the corresponding justification and it is only then that the next one can be typed. When all the hypotheses have been put forward and justified, another window appears on the screen asking the students to type in a blank space the learning issues identified which need to be studied in order to further analyse the case. A final window appears and the students have to type the learning sources that will be used. Students cannot progress to the following phase until they have reviewed the previous working hypothesis, which they can 'maintain', 'reinforce' or 'refute', or 'new ones' can be introduced. Then the program continues to the next phase as previously described.

It is possible to view at any given moment the information already obtained from the PBLS, as well as all the text that has been typed. The program also provides a notepad, which can freely be used as a notebook to take notes or type comments.

This whole process is saved on the hard disk, and cannot be modified. So, it is possible to analyse afterwards the sequence of the working hypotheses and of the questions, with the corresponding justifications, learning issues and learning resources, produced in each session up to the end of the case.

Presently, the students tackle each case in groups of two or three per computer, in sessions lasting around 2 hours. Each case is usually analysed during five sessions with the assistance of a tutor who acts in a similar way as in the traditional PBL session, that is, as a facilitator of the learning process and not as an expert providing answers to the doubts raised by the students[23].

Results

Since the purpose of this article is to describe the development of the program, it was considered appropriate to present the analysis of a problem in the PBLS format, giving examples of the methodology than can be used to analyse the data generated by the students.

The prints were obtained in the last session of each problem, and the following features were considered for analysis: pattern of questioning, hypotheses generated and learning issues identified. Analysis of the prints provided the data to evaluate the 'progression profile' of the hypothesis and learning issues in each case. It was also possible to analyse the sequence of the questions asked by the students and the corresponding justifications and expected answers.

The sequence of the data available on the prints is exactly the same as that followed by the students in each phase, and so it was also possible to identify the factual basis of each hypothesis by relating it to the selected questions and to the information received.

The pattern of hypothesis evolution shown in Fig. 3, which is taken from a case with the initial information '40-year-old woman with fatigue and dizziness', is typical of the majority of the problems analysed by our third-year students. The hypotheses generated in the early phases were maintained or reinforced up to the final phases. It was only then that they were able to reject some and focus on the 'key' hypothesis.

Phases 1 and 2	Phases 3 and 4	Phase 5	Phase 6
Heart failure	→	⊗	
	↑	↑	↑
Anaemia	Menorrhagia-menopause iron deficiency?	Iron deficiency?	Iron deficiency anaemia
Renal failure (uraemia)	→	⊗	
	→	→	⊗
Drug side-effects on CNS	Barbituric/anti-inflammatory intoxication	Anti-inflammatory side-effects	
Malnutrition	↑	↑	↑
		Iron, folic acid, B12 vitamin deficiency	Iron deficiency
Inflammatroy reaction	→	→	⊗
Hypoglycaemia	⊗	Uterine tumour	⊗
			Cyst of the ovary

Figure 3 Working hypothesis-evolution profile. → maintained; ↑ reinforced; rejected.

It is also possible to relate the nature of the questions asked during the different phases of the program to the process of formulation of an hypothesis until its rejection or confirmation. The example taken from the same case illustrates (Fig. 4) this relationship using one of the hypotheses generated by the students – heart failure (HF). In this particular case, the initial hypothesis HF was based on two very non-specific symptoms, 'fatigue' and 'dizziness', freely provided by the program as initial information. During phases 3 and 4, the questions selected were more specific to HF, but two of the patient's signs (cyanosis and oedema) differed from the students' expected results. Despite these facts and the reinforcement of other hypotheses, HF was not rejected until phase 5. This sequence demonstrated that the group needed additional information and knowledge before being confident enough to reject the hypothesis.

From the analysis of the list of the learning issues covered in the initial phases (Fig. 5), we could conclude that, during phases 1 and 2, the students identified 'gaps' in their previous knowledge about HF mechanisms and manifestations, and that the greater specificity of the questionnaire found in subsequent phases was related to the knowledge acquired during the self-learning period.

The sequential lists of the learning issues (Fig. 5) showed that in the first phases of the problem (phases 1 and 2) the students identified gaps of knowledge in a

Phase 1 and Phase 2	Phase 3 and Phase 4	Phase 5
Heart failure ⇒	**maintained** ⇒	**rejected**
• **PRESENT ILLNESS** ⇘	• **REVIEW OF BODY SYSTEMS/PERSONAL AND FAMILIAR HISTORY** ⇘	• **PHYSICAL EXAMINATION**
Chronic + (+)	Dyspnea + (+)	normal blood pressure + (+)
Worsening with exertion + (+)	Oedema - (+)	normal heart exam + (+)
" " bending + (+)	Nicturia - (-)	lower limbs oedema - (-)
	Cyanosis - (+)	cyanosis - (-)

Figure 4 Analysis of the relationships between clinical information and one working hypothesis. –absent/negative; + present/positive; () students' expected answer.

Phase 1 and Phase 2	Phase 3 and Phase 4	Phase 5	Phase 6
Meaning and mechanisms of fatigue and dizziness-organic and psycologic causes			
Mechanisms of heart failure			
Mechanisms of dyspnea/cyanosis			
Mechanisms of anaemia	Alcoholic hepatic disease and anaemia	Iron deficiency symptoms	Reticulocytes in iron deficiency anaemia
Relationship between anaemia and tachycardia	Anaemia of chronic renal failure. Iron deficiency anaemia and megaloblastic anaemia-symptoms	Sideroblastic anaemia	
Chronic renal failure	Progression of chronic renal failure		
Side effects of barbituric and anti-inflammatory drugs	Effects of anti-inflammatory drugs on blood coagulation Ibuprofen-pharmacological	Thrombopenia	
Malnutrition-symptoms and manifestations	Vegetarian diet and mal-nutrition-relationships with anaemia		
Relationship between fever and dizziness. Action of TNF and IL-1		Relationship between fever and inflammation	Meaning of an increased sedimentation rate
Change of posture and dizziness	Autonomic neuropathy-relationship with blood pressure		
Relationship between hypoglycaemia and dizziness. Diabetes	Autonomic neuropathy-symptoms		
	Causes of abnormal menstrual cycle/menopause	Uterus tumours/ovarian cyst-causes/clinical signs	Ovarian cyst-mechanisms of menorrhagia

Figure 5 Learning issues identified during the analysis of the problem.

broad range of subjects. By the end of the second session, which corresponds to phases 3 and 4, the learning issues became much more oriented to a deeper understanding of specific mechanisms. In the last two sessions (phases 5 and 6), the gaps in their knowledge were clearly related to the mechanisms of anaemia, which were the main learning objectives of this specific problem. On the other hand, they also studied a large number of other themes 'triggered' by the analysis of the case.

An open questionnaire was applied at the end of the PBLS sessions in order to evaluate the students' satisfaction with the method and difficulties in the interaction with the computer or with the PBLS. Analysis of the students' opinions revealed that even those with little computing experience found it user-friendly and easy to use, that they considered the practical sessions with the PBLS highly motivating.

Discussion

PBLS was designed taking into account pedagogical and research objectives. Our first concern was to assure that the program provided a user-friendly interface and a structure as close as possible to the PBLM format we used previously, assuming that the students followed the central steps of the PBL methodology. Therefore, the PBLS was divided into the same phases as the written simulations and its contents were essentially the PBLM lists of questions and corresponding answers, allowing the students to establish, within each phase, a free inquiry strategy. The 'gates' acted as challenges (triggers) to recall and apply knowledge relevant to the problem, to formulate and justify a working hypothesis, and to identify learning issues needed to fully understand the problem[16,24].

PBLS is a very simple clinical simulation which provides information about a patient problem mainly in a text format and registers, in free text, the students' performance. In its general conception PBLS can be compared to the Integrated Case Studies (ICS) developed for medical decision making[18]. Although the PBLS does not actually include a significant number of images or charts, which was considered one of the advantages of ICS over traditional PBL, our students' opinions about the program were also very favourable.

The two programs have similar methods to access and provide information in a textual format, have 'gating' rules to progress through the case, display 'windows' in which students introduce free text and provide a record of all the work performed by the students.

In addition to the ICS, the PBLS provides real-time registration of the question selected, its corresponding justifications and its expected answers. It also registers the working hypothesis, the learning issues and resources formulated in each phase. These elements can be easily recovered from records on the hard disk and analysed after the sessions by the tutors, the students or experts in education.

The simulation chosen as an example in this article showed that it was possible to identify the relationships established between facts and working hypotheses, and illustrated how the inquiry strategies were modified after the periods of self-learning. The learning issues identified by our students were oriented to basic sciences, mainly pathophysiology, a pattern similar to that identified by others[12].

The information obtained from the analysis of the prints at the end of each session can be compared to the recently reported 'inquiry trace' methodology[13]. Both methods allowed the 'rebuilding' of a temporal sequence of events from which it was possible to represent the PBL process but not the students' reasoning. However, PBLS further provides written justifications for questions and hypotheses and the expected answers, data that can be difficult to fully recover by observation, due to the dynamics of the conventional PBL sessions. In this particular aspect, we think that PBLS can be a useful tool for those who wish to investigate learning processes occurring during the PBL sessions.

A practical feature of this methodology is that a complete clinical problem, fully analysed by the students in 4–5 sessions, can be printed in a few minutes or directly displayed on the computer screen, which is much less time-consuming than the video methods of registration. Finally, the elements to be evaluated are already written and so the same data can be evaluated by different experts, without previous interpretation.

PBLS was the first original clinical computer simulation designed for PBL teaching in Portuguese medical schools and its implementation in the discipline of pathophysiology occurred without major problems, being easily accepted by the students and the teaching staff. We think that a major factor leading to such an outcome was the long period of planning, development and testing of the program by a multidisciplinary team[19]. Being home-made, it has the advantage of enabling new material to be added to that already existing and the conversion of new clinical problems to the PBLS format.

Furthermore, the PBLS can be used to give feedback to both students and tutors about their performance, thus improving the overall quality of the PBL process.

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