Scaffolding Causal, Diagnostic Reasoning in a Case-Based Learning Environment in Medicine

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Abstract: Medical diagnosis is a critical skill that is usually developed with experience in interacting with, diagnosing, and managing patients. Computer-delivered, case-based learning environments can be developed to provide students with valuable diagnostic experiences prior to dealing with real patients. Diagnostic skill requires physicians to understand and use causal reasoning in order to make predictions. That causal reasoning may be scaffolded in the design of those environments. This paper describes the scaffolding of causal reasoning in making initial diagnoses, determining etiology, and making differential diagnoses in platelet-related problems.

Introduction: Problems in Reasoning

An important purpose of the third year of traditional medical school programs is to bridge the gap between the classroom-based, basic science instruction and clinical requirements of clerkships and residency beginning in the third year. The basic sciences approach, with its emphasis on the inculcation and regurgitation of information, too often results in conceptual misunderstanding of important concepts and oversimplified knowledge when attempting to deal with the conceptual complexity of medicine (Feltovich, Spiro, & Coulson, 1989). Faulty and oversimplified understanding of biomedical principles results in the inability to diagnose complex and non-trivial cases because biomedical content is more complex than the instruction reflects, and the instruction is decontextualized and not properly anchored to the practice of medicine. Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger (1987) claim that the emphasis in the basic sciences on memorization and simplification are antithetical to the development of transferable diagnostic and management skills that are needed by physicians in practice. Biomedical practice requires advanced knowledge acquisition which can most effectively result from instruction that reflects the complexity of the content and embed that learning in the context of solving real-world medical problems (Jonassen, Ambruso, & Olesen, 1991)

In order to bridge this gap, it is necessary to present medical students with authentic, case-based problems to solve, problems that represent the ill-structured nature of knowledge in biomedicine and that require the physicians in training to apply and transfer that knowledge in realistic settings. Ill-structured knowledge has no general rules that describe how to solve most of the cases so there are no defining characteristics to determine the most appropriate action (Spiro et al, 1987). In ill-structured knowledge domains, there are no prototypic cases or they are misleading, that is, certain aspects are differentially important in different cases, in part because of the different context in which each occurs. Each case is novel because of the interactions of symptoms and effects. How is it possible to provide all medical students with these complex case experiences?

Medical schools currently use a variety of methods to teach and assess clinical expertise. There are Patient Management Problems (PMP) which are delivered by workbooks, traditional lecture, simulated patients, and computer-aided instruction (CAI) Case-based learning environments provide a means for engaging medical students in diagnostic, problem solving activities. They provide a more realistic approach than either PMPs or traditional testing methods and are less expensive and dangerous than using regular patients (Solomon, Osuch, Anderson, Gruenberg, Kisala, Milroy, & Stawsky, 1992). They also provide greater flexibility in representing problem situations. That is important, because medical problems tend to be heterogeneous in nature (Palchik, Wolfe, Cassidy, Ike, & Davis, 1990).

Two problems can occur when using case-based learning environments to simulate clinical experience. First, medical problem solving tends to be domain-specific and ill-structured rather than represented by a generalized process. There is a high degree of uncertainty involved in the process of medical problem solving Console & Torasso, 1990). Diagnostic reasoning skills have not been practiced in the first two years of medical school, so students have not developed medical diagnostic scripts. Given the medical students' lack of experience in diagnosing clinical problems and the complexity of the knowledge required to solve problems on different rotations, it is necessary to scaffold the required diagnostic reasoning in the learning environment.

Expert physicians have "illness scripts" which they use to diagnose new patients. They have a rich store of past patients' histories and diagnoses which they have used to build these scripts. They then compare new patients to specific scripts in order to diagnose them. They use pathophysiological reasoning only when they encounter a patient with a new set of symptoms they have not encountered before. This idea of "illness scripts" is similar to the idea of using a hypothesis derived from a plausible solution as a way to solve problems (Simmons, 1992). Thus there is a link that is formed between computer based expert systems which are used to solve clinical problems and the way in which "expert" physicians solve similar clinical problems. It is possible to design computer-based learning environments that incorporate the same causal modeling techniques used in expert systems as a method to teach medical students clinical problem solving skills.

Computer-supported case-based learning environments simulating clinical practice are powerful means of providing students with these experiences because the high-speed computational capabilities of computers can manipulate a large range of variables in order to represent the natural complexity in a real-world system. Among the most effective types of computer-based instruction is the hypertext-based learning environment (Spiro & Jenhg, 1990). A fundamental advantage of hypertext for creating a variety of learning environments is the malleability of its associative structure (Jonassen, 1991). It is possible to map a variety of models onto the hypertext, including semantic relatedness, frames (e.g. problem/solution, functions/uses, action/consequences), cognitive flexibility and complexity models (Spiro, & Jehng, 1990), and also causal modeling.

Causal Modeling

Causal modeling is a generic title for a group of statistical techniques that facilitate the specification of causal linkages among correlations. Causal modeling is used when a decision-maker/problem solver must deal with trying to "resolve questions about possible causes by providing explanations of phenomena (effects) as the result of previous phenomena (causes)..." (Asher, 1983).

Causal judgments involve uncertainty. Uncertainty in judging causality may arise from several sources: an individual's causal knowledge may be incomplete; an individual may lack complete information on the conditions that are present; or more than one alternative may be the cause. Unlike a functional relation which permits bi-directional inferences, a causal relation is asymmetric. Causal relations can be thought of as working assumptions (hypotheses) of the decision-maker or problem-solver, involving hypothetical statements of the "if-then" variety. Systems of this kind can be found readily in engineering and physics, and, to a lesser degree, in social, psychological, and economic systems in order to satisfy deterministic functional relations of the same kind (Asher, 1983).

Causal modeling techniques have been used primarily to represent problem-solving and decision-making in the fields of social science, political science, and physical science due to the cause-and-effect nature of the relationships of the various variables involved in each respective system. For example, the causal modeling approach has been used to analyze variable relationships in the areas of urban unemployment, financial exchange rates, employee turnover government expenditures and national income, student achievement and curriculum evaluation, ethical decision-making behavior; and a number of medical applications such as fatigue syndrome; breast cancer, Alzheimer's disease. Causal models have also found wide application in the fields of artificial intelligence and expert systems.

In the mid 1970s causal modeling was first used in expert systems that attempted medical diagnosis by applying what was called a deep diagnostic approach. Deep diagnostic approaches in expert systems are constructed by representing the ontology of a system, using its genesis to complete a formal methodology for diagnosing a fault within the system. Causal modeling approaches used in such expert systems have a common ground in that they model cause and effect relationships within the system.

Probabilistic causal models may also be applied to systems which require levels of complexity that cannot be adequately represented, since the levels may be either too difficult or impossible to quantify fully. Probabilistic causal models can be used in arenas where the physician does not have adequate knowledge of all the domains involved in the diagnosis, e.g. they may have a limited knowledge of biochemistry when they are dealing with a case where such knowledge might be needed. Probabilistic causal models can be used where some data are missing or impossible to collect or where there are differences in an individual's perception of symptoms related to the underlying disease or in the variations in laboratory results associated with a disease. For instance, where immunity to a particular infectious agent can vary across a population because of genetic differences within the population. In describing newer expert systems, humans often use associative models when they have incomplete information (Console, & Torasso, 1990). Simmons (1992) also uses an associative model which is combined with causal reasoning to create Generate, Test, and Debug (GTD), a paradigm for problem solving which allows for observable features to be associated with a solution to a problem. The solution then becomes the hypothesis to be tested. If the hypothesis is incorrect it is then debugged using causal modeling strategies. Rather than performing the causal reasoning for the medical student, such as with expert systems, this paper proposes that we model the causal reasoning process in the instruction, thereby engaging the learner in the reasoning. A probabilistic causal model was adapted for use in the learning environment described in this paper.

Scaffolding Diagnostic Reasoning in Learning Environments

Learning environments can be produced that scaffold causal, diagnostic reasoning. Scaffolding provides temporary frameworks to support learners in their "zone of proximal development" Vygotsky (1978). Scaffolding enables learners to do what they could not do without the support. Scaffolding may assume the forms of modeling cognitive skills and providing systems of notation, skill development embedded in the design of computer tools, inquiry and alternative assessment (Lehrer, 1993). Research has shown that such scaffolding can supplant deficient reasoning skills and later transfer to new problems (Salomon, 1979)..

Solving medical problems requires modeling the uncertainty of each decision point, that each decision has many options and that each option has a different likelihood of occurring, based on previous decisions. According to Kuipers (1985), a "...causal model of a disease process and its evolution over time provides additional constraints that allow incompatible combinations of hypotheses to be excluded." The complexity of the problem solving task and the uncertainty of the content are a natural part of the required causal reasoning and are best learned in learning environments that emphasize flexible learning by the learners and that initially model or scaffold the causal reasoning required to solve the problem.

When trying to make a decision or solve a problem within a particular disease context, physicians need to evaluate and understand the causal connections between a number of different variables acting simultaneously to produce the disease symptoms. However, it is usually impossible, except through a lengthy research agenda, to collect the data that would permit a precise specification of the effects of variables on each other and their interactions. Those data often are impossible to collect and they tend to provide correlative relationships but not causal ones. However, based on research in the field, we can model the cause-and-effect relationships necessary to accurately describe the diagnostic problem-solving process in any medical domain. Causal modeling is an appropriate tool for representing this reasoning.

Using Causal Modeling to Scaffold Diagnostic Reasoning in a Case-Based Learning Environment in Transfusion Medicine

As more and more knowledge is accumulated in the field of medicine, practice of specialty areas becomes more complicated. An area where this is especially true is transfusion medicine. In the past, teaching of transfusion medicine has not been well represented in medical school curricula, where it has traditionally been taught to medical students as part of a hematology course, or as an addendum to specialties where transfusions were often needed. Transfusion medicine includes those disciplines in medicine which are involved with the collection, processing, and storing of cellular and acellular components of blood, the administration of blood components and products, and the survival and function of the elements in transfusions. The field is very broad and encompasses a number of basic sciences, including biochemistry, immunology, physiology, and clinical areas, such as hematology, surgery, internal medicine, and pediatrics. This module focuses on the role of platelets in controlling bleeding, disease states in which platelet counts are low or function is abnormal, and platelet transfusions are required to treat these diseases states.

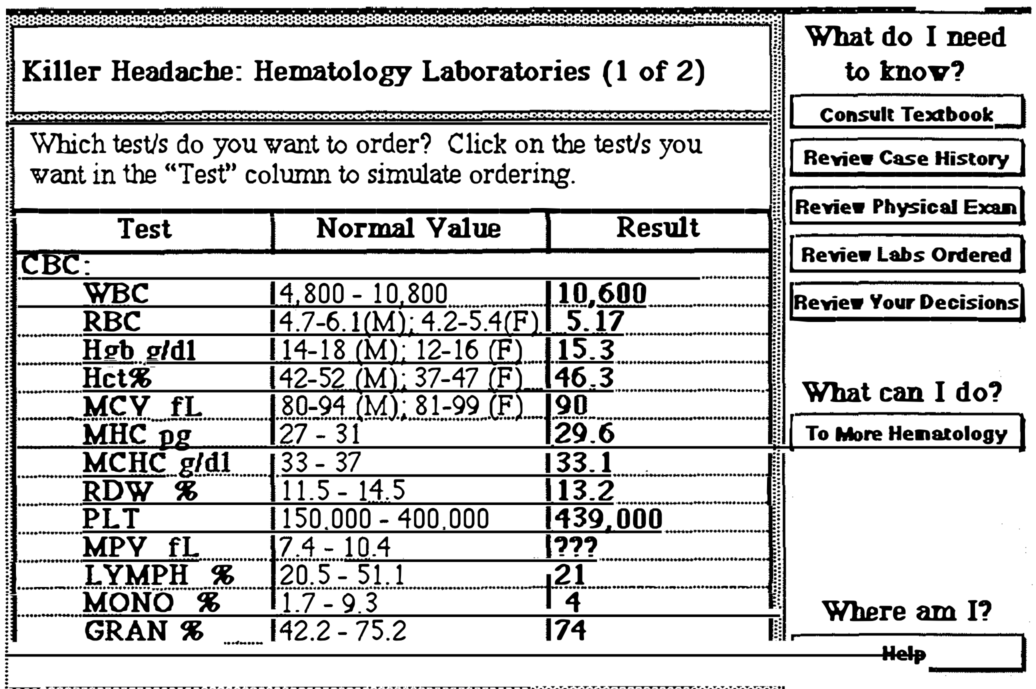
While solving clinical problems in the learning environment, the student must:

- Define a cause for a patient's bleeding with the choices being: anatomic (due to blunt trauma, laceration, or bleeding from a surgical wound, decreased number or abnormal function of platelets, or plasma procoagulant activity such as diminished coagulation factors.
- Describe the etiology of the disease in terms of an understanding of the processes leading to low platelet counts or abnormal function.
- Diagnose the specific disease state(s) responsible for the bleeding.
- Provide a strategy for patient care, follow-up, and treatment (e.g. transfuse platelets or not transfuse platelets).

Each of these steps entails a different set of causal factors which had to be identified in the analysis phase of the project. In order to provide feedback to learners at each stage, a causal model of the entire process was developed (space will not permit an illustration of this model, which will be presented at the conference, if the paper is accepted). For instance, if the student selected a particular etiology, they would be told that based upon medical research, there was a certain percentage probability that their selection was correct. Our attempt was to reflect the uncertainty in the causality of the diagnostic process. However, medical research has provided mixed research results regarding each of these decision factors, so attributing specific regression weights or probabilities to each cause-effect relationship is impossible. Therefore, causal-effect decisions were separated into four classes of probability (not a cause, possible cause, probable cause, definitely a cause). At each decision point while working through the case, learners were required to select a cause, etiology, or diagnosis and then to support their choice by identifying the causal agents. This is the part of the diagnostic process that was most directly scaffolded. Learners were required to justify their decision based upon causal reasoning by selecting the probable features that led to their decision, much as they would be required to do in rounds.

Mapping Causal Models onto Cases

For each of five cases in the hypertext, learners are first presented with a case history and the results of a physical examination. They next have the option of ordering lab tests, reviewing that information, or selecting an initial diagnosis. If they choose to order labs, they are presented with a series of options (Fig. 1) and receive coaching along with test results if they select anything but hematology tests at this early stage in the diagnostic process. If they select hematology tests, they receive information about both the normal


Killer Headache: Hematology Laboratories (1 of 2)

Which test/s do you want to order? Click on the test/s you want in the "Test" column to simulate ordering.

Test	Normal Value	Result
CBC:		
WBC	4,800 - 10,800	10,600
RBC	4.7-6.1(M); 4.2-5.4(F)	5.17
Hgb g/dl	14-18 (M); 12-16 (F)	15.3
Hct%	42-52 (M); 37-47 (F)	46.3
MCV fL	80-94 (M); 81-99 (F)	90
MHC pg	27 - 31	29.6
MCHC g/dl	33 - 37	33.1
RDW %	11.5 - 14.5	13.2
PLT	150,000 - 400,000	439,000
MPV fL	7.4 - 10.4	???
LYMPH %	20.5 - 51.1	21
MONO %	1.7 - 9.3	4
GRAN %	42.2 - 75.2	74

Fig. 1. Lab tests

values and the patient's results. With this information, they are ready to select an initial diagnosis from a list of options including anatomic, platelet, or plasma procoagulent proteins. Following their selection, they must support their diagnostic reasoning by identifying the case findings that support their decisions, that is, that were causal agents of the bleeding episode(s) (Fig. 2). This causal reasoning process is what we determined was important to scaffold in novice diagnosticians. Such scaffolding requires communicating the process to the learners, coaching it, and eliciting articulation the ideas (Guzdial, 1994). These activities are operationalized by having learners click on the radio buttons that indicate the degree to which various pieces of evidence (darkened buttons) support their diagnosis. That is, they have to justify the causes that lead to their diagnosis. They then receive expert feedback on their selections and an expert summary of the diagnosis. We communicate the process through instructions to "defend" their thinking. We coach their performance through a simple interface and expert feedback. The entire process requires that the learners articulate their thinking that resulted in their diagnosis. Another important feature of scaffolding is fading, so that students learn to perform without scaffolding. Scaffolding in our case-based learning environment is accomplished by removing the causal prompts in the last two of six cases.

Following the initial evaluation, the learner proceeds to determining the case etiology, whether (in this case) the (platelet) problem resulted from increased destruction or reduced production of platelets. As always, the learner may review the case history and physical examination information, order additional labs, consult the textbook, or get help. Following review of the facts of the case and cause of the bleeding, the learner is once

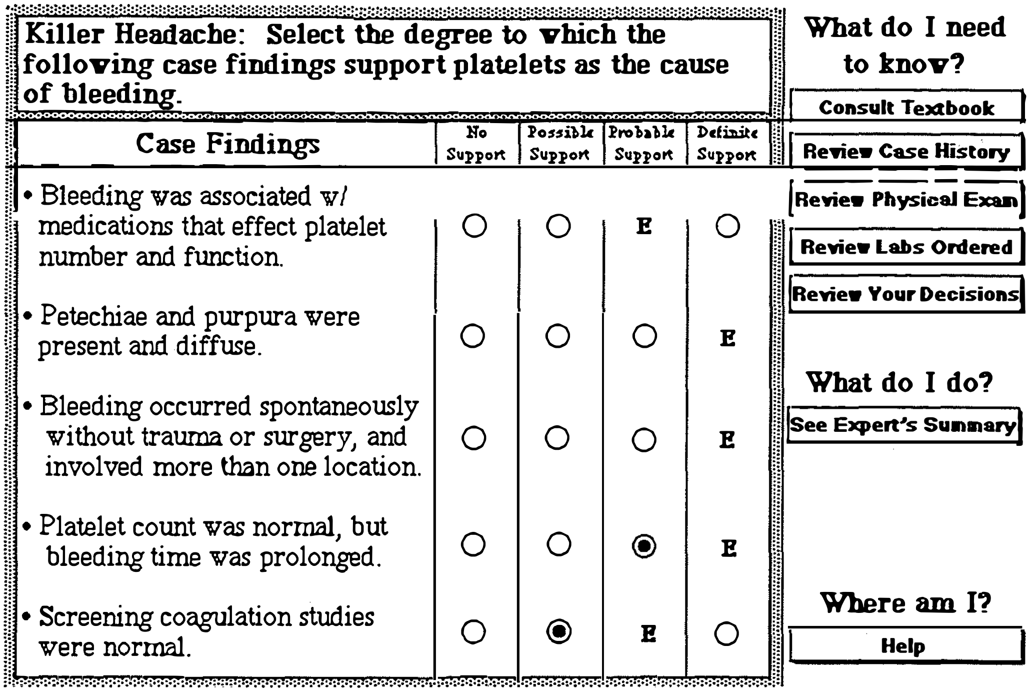


Fig. 2. Defending causal reasoning.

again required to support their reasoning for a specific etiology, thereby scaffolding the etiology diagnosis process. Having defined the etiology of bleeding, the student determines and defends the differential diagnosis of the specific disease, then proceeding to treat the case. In addition to preventative care and general support, the learner may order a transfusion of platelets (Fig. 3). At each point in the diagnostic process, including the ordering of blood products, the student must justify their decision or action. Following their prescription, learners have the option of changing their treatment, ordering additional platelet transfusions after reviewing labs, physical and history. Or the learner may simply close the case, at which time they receive a medical summary of the actions and causes present in the case.

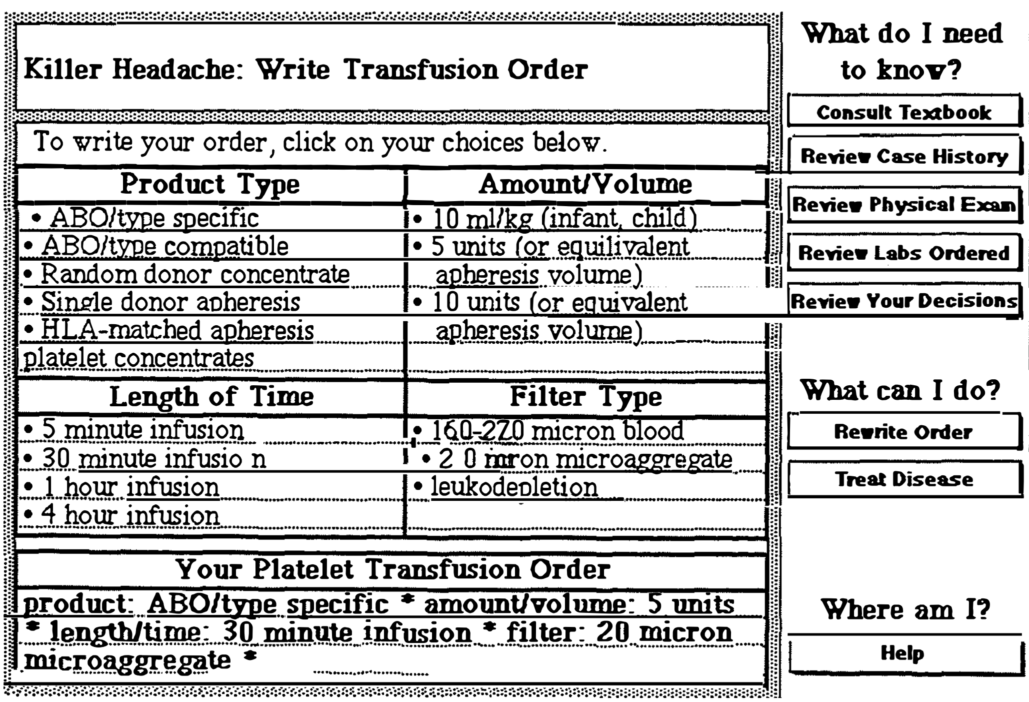


Fig. 3. Writing transfusion order.

The causal modeling is embedded in the options presented, the selections made, and the diagnostic reasoning is scaffolded in the justifications required at each decision point in the case. The causal reasoning is made an overt process rather than the covert process that most experienced physician go through. Extensive use of reasoning in simulated cases will transfer to less related cases in the future.

This environment has been used in a third year medical education program at a medical college in the west. For political reasons, it has been impossible to date to conduct research on its efficacy.

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