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Scripts and Medical Diagnostic Knowledge

Theory and Applications for Clinical Reasoning Instruction and Research

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Abstract

Medical diagnosis is a categorization task that allows physicians to make predictions about features of **clinical** situations and to determine appropriate course of action. The script concept, which first arose in cognitive psychology, provides a theoretical framework to explain how medical diagnostic knowledge can be structured for diagnostic problem solving. The main characteristics of the script concept are pre-stored knowledge, values acceptable or not acceptable for each illness attribute, and default values. Scripts are networks of knowledge adapted to goals of **clinical** tasks. The authors describe how scripts are used in diagnostic tasks, how the script concept fits within the **clinical reasoning** literature, how it contrasts with competing theories of **clinical reasoning**, how educators can help students build and refine scripts, and how scripts can be used to assess **clinical** competence.

Introduction

A female patient, hospitalized for severe back pain, is discovered to be hyperglycemic. An endocrinologist, consulting on what he thinks is a glucose-adjustment problem, looks carefully at the patient's face, then at her hands and arms, and says to the resident "this is a case of Cushing's syndrome." The puzzled resident asks the consultant to explain his conclusion. "The patient," the consultant replies, "is 44 years old, female, with a probable pathologic fracture of a vertebral body; this is uncommon for that age. She is obese, but this obesity is central, with sparing of the extremities. She has a moon face with mild facial hirsutism. The skin seems thin and dry, and the arms are covered with bruises. With all these signs, it is improbable that we are facing common obesity or type II diabetes. I am pretty sure that she has Cushing's. I will order some tests to confirm this hypothesis."

Any clinician can recall similar instances of quick **reasoning**. In this case, the consultant went into the room with an initial hypothesis; after a quick look at the patient, a new hypothesis popped into his mind. This kind of **reasoning** implies an amazing sequence of psychological events: perceiving the features of the situation, quickly accessing relevant hypotheses, checking for signs and symptoms that confirm and rule out those competing hypotheses, and using related knowledge to guide appropriate investigations and treatment. These events happen at such a high speed that students have trouble understanding the **reasoning** process and perceive only the outcome.

This sequence of events raises questions about the structure of **clinical** knowledge in a physician's memory. The concept of "scripts," first introduced in medical literature by Feltovich and Barrows[1] and evolving ever since, describes the structure of **clinical** medical knowledge. Our goal in this article is to present to medical educators how scripts as a memory structure might be organized for diagnostic tasks. We think that this theoretical framework warrants research to test its plausibility and that it has the potential to assist educators to more efficiently teach and assess **clinical reasoning** skills.

In this article we (1) present the psychological context of scripts, (2) illustrate how they apply to diagnostic tasks, (3) explore how this theoretical framework fits within existing **clinical reasoning** literature and contrasts with competing theories, (4) suggest avenues for future research, and (5) describe implications for **clinical** education and assessment.

Psychological Context

Diagnosis as Categorization

Diagnosis is at the core of medical practice. Even in emergency situations, clinicians will not order investigations or begin treatments before they have a rough idea about what is occurring. Cognitive psychologists consider diagnosis a categorization task[2,3] that consists of placing patients' illnesses in different classes based on their attributes.[4] Once clinicians recognize a patient's illness as belonging to a given class of diseases, they can use related knowledge to take actions such as providing a prognosis, planning an investigation, or instituting a treatment.

Hypothetico-deductive Reasoning

The classic model of **clinical** diagnosis is the hypothetico-deductive model.[2,5,6,7] It is characterized by the generation of multiple competing hypotheses from initial patient cues and collection of data to confirm or refute each hypothesis. If the endeavor is unfruitful, the clinician creates and investigates new hypotheses in an iterative process of hypothesis generation and testing. This model, which represents a description of the mental *processes* used by clinicians, has been repeatedly validated by empirical studies[5,6,7,8] and underlies most modern **clinical** instruction.[9,10,11] However, the psychological mechanisms responsible for the generation and testing of relevant hypotheses remain largely unknown. According to many researchers and theoreticians,[1,12,13,14,15,16,17] explanations should be found by exploring physicians' knowledge bases, in terms of both *content* (the specific knowledge for any topic) and *structure* (the organization of the knowledge). The script concept offers one model of such a structure.

The Nature of Scripts

The basic principle underpinning the script concept asserts that, to give meaning to a new situation in our environment, we use prior knowledge that contains information about the characteristics and features of the situation and information about the relationships that link those characteristics and features. In other words, incoming information activates a previously acquired network of relevant knowledge and experience—*a script*—that directs the selection, interpretation, and memorization of that new information.[18,19] In medicine, when a physician sees a patient, he or she perceives features—symptoms, signs, and details from the patient's environment— that activate networks of knowledge that contain those features and their relationships to illnesses. Those networks of knowledge then provide context, and thus meaning, to the new situation.

The script concept is a variant of a more general concept, that of schemas.[20] Schemas are goal-directed knowledge structures adapted to perform tasks efficiently.[21] Scripts are schemas associated with sequences of events that occur frequently in a specific order,[22] and knowledge about illnesses includes information about the spatio-temporal sequence of events in illness development.[1] Considering that most of the properties of one concept apply to the other, we use "scripts" to describe properties of both schemas and scripts. Schmidt, Norman, and Boshuizen[23] have described a theory of development of **clinical** competence that hinges on the concept of illness scripts. In the next part of this article we focus on one **clinical** task—diagnosis—and explain how scripts may be organized to do this task efficiently. The portion of an illness script that is adapted to diagnostic tasks could be called a "diagnostic script."

Scripts and Diagnosis

Smith[24] has provided insights into how scripts can be adapted to a diagnostic (categorization) goal. A script can be described as a set of attributes, each of which can be instantiated by values that have more or less probability of occurring. For each attribute, the value that has the greatest probability of occurrence is the default value. Table 1 contains an example of a script that a physician might have about maxillary

sinusitis. The script contains attributes (for example, pain location) for which different values are possible (no pain, dull sensation, infraorbital pain). In any given instance, only one of the values can fill the slot. Until the physician determines otherwise, the default value (in this case, infraorbital pain) is assumed to be present.

Two other characteristics of scripts are important. First, the information belonging to a script is not exclusive. Symptoms and signs (unless pathognomonic) can belong to several scripts. The particular script for an illness is characterized by the set of signs and symptoms it contains and by the relationships that link them. It consists of information related to this illness. Second, scripts are generic structures that can represent any instance of an illness. Each medical encounter implies an instantiation process; that is, the finding of the actual values of the attributes observed in the patient.

In 1980, Barrows and Tamblyn[25] described a model of **clinical reasoning** that represented a synthesis of works of several researchers.[2,3,4,5,26] From the main characteristics of that model, which is a classic in the **clinical reasoning** literature, we describe how the script concept provides an explanation for this **reasoning** process.

Hypotheses Generation—Activation of Relevant Scripts

At the beginning of an encounter, the physician perceives instantly and almost unconsciously verbal and nonverbal cues from the patient; within moments hypotheses pop into the physician's mind as possible explanations for the patient's problem. The hypotheses, which are usually a product of the clinician's past experiences and knowledge, appear quickly, and their activation is an "unconscious act of memory association."[25] This description fits well with script theory, which postulates that script activation is an automatic process, called "script triggering."[27,28] Grant and Marsden[29] have shown that **clinical** memory structures are triggered by the clinician's recognizing relevant items of information.

Scripts as Meaning Providers

Very quickly the clinician builds a representation of the situation that initiates the direction and scope of the **reasoning** process.[25] The main function of scripts[30] is to construct interpretations of situations. A set of relevant scripts is activated from the cues perceived, and the activity is then to find whether one of the activated scripts adequately fits the **clinical** findings. This verification requires that values be assigned to the different attributes. If the physician can not adequately fit an activated script to the findings, he rejects it and begins to verify another one. Hence, according to the script concept, the fundamental aspect of understanding a situation is a hypothesis-testing activity.

The activation of a script provides access to a set of attributes and allows an active search to find appropriate values. This process is called "script processing."[28] There appears to be no fixed order for checking a script's attributes; individual clinicians proceed in different orders. This accounts for the variability in data collection observed among clinicians. Different people rarely use the same set of questions to solve any one

clinical problem.[2,31] Experienced physicians ask questions and do physical examinations that are most efficient according to their own activated scripts.

Reasoning with an illness script is hence hypothetico-deductive, but not in a very conscious way. The activation phase is usually automatic, while the processing phase—the search for evidence to rule hypotheses in or out—is controlled and deliberate.

Scripts as Organizers of the Flow of Clinical Information

The set of hypotheses considered by a physician in a given **clinical** situation guides the physician's interview and examination of the patient. It represents the initial possibilities that he or she feels need to be pursued. Many physicians are unaware of the existence of these processes, but observation of their **reasoning** shows that the questions they ask and the items of physical examination they perform are, for the most part, specifically chosen to rule in or rule out, or at least strengthen or weaken, the likelihood of the hypotheses they have considered.[25]

An important characteristic of the script concept is default values.[24] Among the acceptable values for each attribute, one is assumed to be present until a value has been specifically verified. This explains why clinicians do not always look for all signs and symptoms. When they have enough evidence to establish their diagnoses, they often assume that other values are present and do not specifically check them (in the example in Table 1, if a patient has an acute nasal obstruction and pus emanating from middle meatus, the physician may not do percussion over the infraorbital area). Default values are also important for communication between clinicians. When a physician discusses a patient's diagnosis with colleagues, he or she need not explicitly specify all attributes of the illness; the colleagues will build a picture of the patient using their own scripts, filling in gaps with the default values. For instance, if a clinician speaks of a patient with maxillary sinusitis, he or she will mention only the signs and symptoms that differ from a typical presentation.

In addition to knowledge about **clinical** features of illnesses, scripts contain knowledge about appropriate actions to take. For example, if a child presents in acute and rapidly progressing respiratory distress with a high fever and odynophagia, many clinicians will act as if the child has epiglotitis until contradictory information appears. This leads them to make inferences, some of them related to diagnosis (for example, detection of a large epiglottis on lateral x-rays), others related to management of the condition (for example, to bring the child to the operating room for nasotracheal intubation).

As the encounter with the patient progresses, a large amount of information accumulates. The major difference between students and experienced clinicians is that, when asked for a summary of the patient's problem, students tend to recite endless amounts of data about **clinical** findings, while experienced clinicians are able to summarize the patient's problem in a way that captures the significant information obtained.[25] Scripts also provide an explanation for this process, because their structures, each with its set of attributes, serve as organizers. Coughlin and Patel[32] have provided evidence for the existence of illness scripts as organizers in memory. They presented medical students and physicians with both organized and disorganized (random) texts describing disease histories. In recalling both the organized and the disorganized versions of the same cases, the physicians reported the information in the same script-like order, while students showed much less organization.

Assessment of the Fit between a Script and a Given Clinical Situation

According to the script concept, during the data-collection process, physicians systematically fit incoming information to the script's attribute slots.[24] For each slot, there are acceptable and unacceptable values. If unacceptable values are found, the script is rejected (for example, the maxillary sinusitis script would be rejected if a history of bloody rhinorrhea were discovered), and other scripts that accept that value are activated or reinforced (for example, maxillary sinus cancer). Among acceptable values for an attribute, some bring more weight to a hypothesis than others. The default value brings the most weight for the hypothesis; unusual values bear less weight.

The assessment of each value in the activated scripts explains the moving status of the set of hypotheses in an encounter. Hypotheses can be reinforced, or be attenuated, or disappear, while others are activated.[25] The accumulation of acceptable values within a script raises the level of activation of that script, and at a particular moment, the clinician decides that there is enough evidence to bring closure to the diagnostic process. He then settles on a definitive or working diagnosis, depending on the situation.

Scripts and Clinical Reasoning Literature

The **clinical reasoning** literature contains several competing theories. We now describe how the script concept stands among them.

Patel and Groen[40] asked both expert and novice clinicians to describe aloud their processes of **reasoning**. They argue that experts reason forward, from data to diagnosis, while novices reason backward, from hypotheses to data. Their view, though often cited in the medical **reasoning** literature, has several arguments against it. First, even in their own research, the authors did not always find this effect, and in cases where information is available only sequentially (e.g., interactive tasks), working forward may be impeded. Second, Eva, Brooks, and Norman[41] showed that differences in the talk-aloud protocols of experts and novices may reflect differences not in **reasoning** strategies but in explanatory ability or confidence. Using a within-subject design, they found that responses appeared to vary between forward and backward **reasoning** strategies depending on both the amount of information available before the responses were requested and the degree of confidence the participants had as a result of previous feedback. Last, in a script-concept perspective, script activation is hypothesis generation, while the verification is the deduction. The more easily the script can be activated, the more automatically information can be taken in, the more it looks like forward **reasoning**. Then, when activation stops, some verification has to take place, and the process looks like deduction and backward **reasoning**. Sometimes the verification part can be very effortless, as the physician in the introduction shows.

Elstein and colleagues[2] have pointed out that representing a problem through hypotheses generation is a psychological necessity due to the complexity of **clinical** situations, the enormous amount of data that is potentially available, and the limited capacity of working memory. In unfamiliar, complex situations, experts constrain the problem by generating manageable sets of **clinical** interpretations and then use them in an active and

conscious way to do an oriented data collection aimed at confirming or refuting the corresponding hypotheses.

Grant and Marsden[29,31] have confirmed that clinicians actively process **clinical** information, recognizing items of information that act as keys to particular memory structures. These structures, in turn, dictate particular interpretations. Those interpretations then begin a search for confirming or excluding features, a search governed by the precise contents and organization of knowledge in memory.

In Bordage's studies of diagnostic thinking,[33,34] the more astute diagnosticians are those who build global representations of the case based on the relational structure of their medical knowledge in long-term memory. Their knowledge is organized not only as simple lists of signs, symptoms, and rules, but as a rich network of knowledge held together by abstract relationships. These relationships are used to interpret similar and opposing bits of information in memory. In contrast, weaker students operate from disjointed lists of signs and symptoms, where the basic diagnostic strategy is to include or exclude disorders as signs and symptoms come and go. Hence the major determinant of diagnostic competence is the capacity to compare and contrast the signs and symptoms presented, transferring the patient's findings into abstract qualities that relate to stored memory structures.

The script concept implies that as individuals repeatedly perform tasks, they reorganize their knowledge to do the tasks as efficiently as possible and with the most economic cognitive processing. For Feltovich,[35] the development of expertise is largely a matter of reorganizing knowledge and cognitive processes to perform tasks. "Experts restructure their inner working-knowledge and procedures for efficient application in their work-a-day environment." In a categorization task, individuals use perceived features of objects or situations to place them in categories. Such a task requires knowledge about the perceptible features of objects or situations and on their relationship within categories.

Authors differ in their conceptions of script structure. According to Feltovich and Barrows,[1] a new script is constructed during each **clinical** encounter. Scripts, then, are temporary mental representations consisting of existing knowledge and new information. They contain three parts: enabling conditions (features associated with the acquisition of illness, e.g., fatigue or hereditary factors); fault (malfunctions in illness, e.g., invasion of tissue by pathogenic organisms or metabolic disorders); and consequences of faults (signs and symptoms). This conception of scripts implies that **clinical reasoning** is a mix of causal and associative **reasoning** and script is a mental model of the situation, which allows the clinician to efficiently generate hypotheses and strategically gather data. In script processing for assessment of a fit, according to this conception, patient **clinical** features never perfectly match the attributes of an illness scripts. Scripts work in such a way that a physician makes a "reasoned decision" about why some expectations are violated.

Our concept of scripts differs from that of Feltovitch and Barrows in at least four major respects: (1) scripts are pre-stored knowledge structures, (2) they are activated almost unconsciously from initial **clinical** clues, (3) they are made of known links among **clinical** features, including enabling factors, fault, and consequence, and (4) they function by memory association, not by causal **reasoning**.

Patel et al.[36] and Schmidt et al.[37] have shown that, when medical students solve **clinical** problems, they reason causally based on their biomedical knowledge. During their pre**clinical** studies, they progressively build rich and elaborated networks explaining the causes and consequences of disease in terms of general underlying pathophysiologic processes. These studies have also shown that the explicit use of biomedical knowledge in **clinical** problem solving decreases with expertise. Boshuizen and Schmidt[13] explain this phenomenon as experts encapsulating biomedical knowledge by subsuming low-level, detailed biomedical knowledge into high-level, simplified causal models.

Thinking causally to carry out a categorization task is cognitively demanding.[43] It is more efficient to use known associations between **clinical** features and illnesses. Hence, when students begin to see patients and are confronted with constraints of time and efficiency, they progressively acquire illness scripts. According to Schmidt, Norman, and Boshuizen,[23] these structures encode the signs and symptoms of illnesses, with their relationships, their ranges of variation, and the enabling conditions. The use of these structures is very efficient because (1) their activation is automatic and almost unconscious (triggering of scripts), (2) the activated scripts are then used in a conscious and strategic way to confirm or refute the corresponding hypotheses (script processing), and (3) in so doing, activated scripts serve to guide information selection, memorization, and interpretation. Biomedical knowledge remains, nevertheless, present and accessible. It places constraints on the acceptable values for the different attributes of scripts and on their relationships.[1] It also alerts clinicians when they find abnormal findings or events that violate normal physiologic expectations, serving as a coherence criterion for hypotheses about the patient.[38] Biomedical knowledge is also used in situations where scripts are not found. In such cases, clinicians use their biomedical knowledge to understand the situation and to find pertinent hypotheses through a chain of causal **reasoning**.[38] According to these theories, knowledge used in **clinical** tasks can be conceived as a structure with two "layers" that are strongly interrelated. One is a layer of biomedical knowledge that is used in unfamiliar or atypical cases; the other a layer of specialized knowledge (the diagnostic scripts) that is used in familiar or typical cases that do not require causal **reasoning**, allowing quick and efficient performance.[23]

According to Schmidt, Norman, and Boshuizen, physicians store memories of previous patients and, to a large extent, expert **clinical reasoning** is the comparision of the current patient with a previous patient—and the recognition of similarities. Brooks, Norman, and Allen[39] have provided empirical evidence of the importance of similarity in **clinical reasoning**, but the place of similarity can be discussed in the script perspective. Similarity, instead of being the whole mechanism of diagnostic **reasoning**, may also be a way of script activation, which might be followed by script processing to check for the presence or absence of features that will allow the clinician to confirm or reject the diagnosis. This alternative explanation illustrates that the script theory has the potential to explain empirical evidence from other conceptual frameworks, but illustrates also the need for research to explore it.

Avenues for Future Research

Bordage and Williams[42] have recommended a practice-theory-practice approach for

research in medical education, in which questions pertinent to educational practice are built in the context of existing theory, and results are interpreted to confirm or refute these theories. This in an iterative conception of research where practice is used to formulate and refine theory, which in turn guides practice. Finding ways to help students to become efficient in solving patients' problems is a central issue for medical educators. Research has shown that organization of knowledge is the key in the construction of **clinical** expertise. The script concept explains many features of medical diagnosis and provides a theoretical foundation on which **clinical** education can be based. Therefore, there is a need for more research to validate this theoretical construct and to determine its effective contribution in the diagnostic process. To illustrate how this endeavor can be pursued, we describe here three research issues that are central in the script concept and how they can be addressed.

The first issue concerns the nature of the links within **clinical** knowledge networks. Do clinicians use associative links within pre-stored knowledge structures in familiar diagnostic tasks in contrast to causal **reasoning** in less familiar situations? A method of addressing this question might be to recruit expert physicians to treat simulated patients in contexts as authentic as possible. These experts would have to solve problems from their domains of expertise, some being typical and familiar, others being atypical and unfamiliar. In both situations, they would be asked to make their diagnostic processes explicit, by thinking aloud, and would be asked to describe the rationales that justified their **clinical** decisions. Content analysis of protocols would allow examination and contrast of the organizations of knowledge they used in both situations.

A second issue concerns the concept of default values, which is crucial within the conceptual framework of scripts. If, among the acceptable values for each **clinical** attribute, one is assumed to be present up to the moment when values of the attribute are specifically verified, and if clinicians close their diagnostic inquiries when they have enough evidence to make a diagnosis, then they should make inferences concerning the values of the attributes they have not specifically checked. Research in this area has provided evidence to sustain this concept.[43] After having read paper-based cases, physicians were asked to remember or recognize **clinical** features, some that were present in the text, others that would result from inferences (false recognition). The authors found only a few instances of false recognition. An explanation to this finding could be that the process of getting **clinical** information is very different in an authentic **clinical** encounter than in a paper-based case. In the latter situation all information is present, in a written form, while in the former information has to be specifically sought and can be neglected if the clinician finds that he or she has enough information to reach a diagnosis. Therefore, research protocols using real or simulated patients might reveal a phenomenon that was not evident on paper-based cases.

A third issue concerns the dynamic or stable nature of scripts. According to theory,[30] scripts are dynamic structures, modified by each new encounter. The memory of an encounter consists of some combination of specific information stored about that experience and of general information about the illness contained in the relevant script. Obviously the *n*th encounter with a similar illness will not modify the relevant script significantly, but the encounter of a rare illness or of an atypical presentation of a common illness will have more effect on memory. Experimental studies of the issue of different effects of encounters on memory structures, depending on the rare or familiar nature of illnesses, require manipulation of previous experience in a domain. However, to compare experts' and non-experts' performances in diagnostic tasks while controlling

experience as an independent variable is difficult to achieve, because if experts do not have experience for a specific task, they can no longer be qualified as experts. This implies the development of new scripts about illnesses that are authentic, that are related to the previous knowledge of the expert, but with which they have no previous experience. Research exploring scripts of illnesses that are rarely seen in a particular geographic area, such as malaria in Holland, could overcome these difficulties.

Scripts and Clinical Reasoning Instruction and Assessment

The conceptual framework of scripts raises a series of educational issues concerning (1) the period of script construction that is optimal within curricula, (2) the instructional methods that foster their construction and refinement, and (3) their implications for the assessment of **clinical** competence.

According to Schmidt, Norman, and Boshuizen,[23] illness scripts emerge when students are exposed to real patients. In their first encounters, they apply their biomedical knowledge. They consciously relate symptoms to concepts in the relevant pathophysiologic networks they possess. Diagnosing their first **clinical** cases requires a lot of mental effort. While they begin to assume the full pressure of patient responsibility,[25] a transition takes place from a kind of knowledge fitted to description and explanation tasks to knowledge structures adapted to **clinical** tasks, i.e., diagnostics, management, treatment, and prognosis.

Such a developmental sequence is not inescapable and may reflect a conception of medical training where biomedical knowledge is built first, and then **clinical** knowledge, as has traditionally been the case in medical education.[44] In fact, the acquisition of diagnosis scripts could be undertaken at the very beginning of medical curricula, and there is a trend in contemporary method of instruction to early exposure to authentic professional tasks; therefore, the desirability of waiting until clerkship to begin the development of scripts adapted to diagnosis tasks is questionable. Early exposure can help students to develop scripts very early and help them to incorporate biomedical and **clinical** knowledge that they would acquire subsequently within their scripts, if appropriate care is taken about integration of this knowledge. This is in accordance with principles of situated learning. In contrast to such a strategy is the more traditional conception that the construction of biomedical knowledge is a critical foundation phase of medical training and that an early construction of diagnosis scripts would threaten the construction of a strong base of biomedical knowledge.

Whether scripts are built early or later in curricula, their acquisition and refinement cannot be left entirely to the variability of **clinical** exposure. Knowing that elaborated and organized knowledge is the key to **clinical** expertise, **clinical** teachers should explicitly assist students in the construction of efficient and well-structured knowledge bases. Such a knowledge bases. Such a knowledge base allows students to give meaning to **clinical** situations, to guide their **clinical** inquiry, to interpret **clinical** information in order to reinforce their hypotheses or weaken them, to activate new ones because entertained ones are not fitted to the situation, and to decide when they have enough data to close the diagnostic process. Educational methods adapted to the requirements of

clinical settings have been described.[45,46] They follow a series of principles established from cognitive psychology[47]: (1) learners actively engage in the educational activity (scripts cannot be transmitted directly from teachers' mind to students' minds; they have to be constructed by each learner); (2) new information is articulated on students' prior knowledge (this implies the activation of prior knowledge); (3) intermediate stages of **clinical reasoning** are made explicit; (4) students are asked to use their **clinical** knowledge to assess incoming **clinical** information and, in so doing, to reinforce or reject entertained hypotheses; and (5) acquired knowledge is validated through its use with peers and teachers.

Another educational consequence of the script concept is its potential usefulness in assessing **clinical** competence. Contemporary methods of **clinical** assessment have repeatedly shown the puzzling fact that experienced clinicians score little better and sometimes worse than less experienced clinicians or students.[48] A possible reason for this is that most methods measure **clinical** factual knowledge rather than the organization of knowledge that allows clinicians to recognize and handle situations effectively. In so doing, they place experts, whose strength is organization of knowledge rather that linear accumulation of knowledge, at a disadvantage.

In Bordage's studies of diagnostic thinking,[33,34] the efficient diagnosticians are those who build a global representation of the case based on the relational structure of their medical knowledge in long-term memory. Their knowledge is organized not only as simple lists of signs, symptoms, and rules, but as a rich network of knowledge held together by abstract relationships. Assessment tools have been tested that place clinicians in specific contexts and probe their capacities to interpret data in the perspective of activated hypotheses. These "script assessments"[49,50] appear to be reliable tools that allow discrimination among individuals on the basis of their **clinical** competence. Scores obtained from these questionaires are higher for the clinicians who have more experience in the field, which is what one would expect from a valid assessment tool of **clinical** competence.

Conclusion

Script conceptual framework implies that when clinicians see a patient, they search their memories for an appropriate script, and instantiate it with the specific information provided by the case. So problem solving, at least in routine cases, is a process of script search, script selection, and script verification.[23] Scripts are pre-stored knowledge structures that are used to actively process **clinical** information to confirm or eliminate the diagnostic hypotheses the clinician has in mind at a given moment, and collected information is constantly checked with predetermined values to assess for a fit. Scripts are organized for specific tasks. Because diagnosis is at the core of medical practice, an important part of the acquisition of expertise is related to script construction. In this perspective the acquisition of medical expertise consists in building, refining, and linking scripts that allow students to become active processors of **clinical** information instead of simple collectors of as much information as they can get, without giving meaning to it.

Much evidence already favors the script conceptual framework's ability to explain and predict medical performance; still, there is a strong need to enrich that body of evidence. The framework helps medical educators because it focuses on the progressive construction of elaborated knowledge,[51,52] knowledge that is refined throughout a clinician's professional life. For the development of **clinical** competence, organization of knowledge is as important as its acquisition. The framework offers a model of what kind of knowledge organization sustains **clinical** competence. It may therefore guide **clinical** instruction. It is also a concept that opens a field of assessment of **clinical** competence that is practice-based and overcomes some limitations of existing methods of assessment of **clinical** competence.

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References

1. Feltovich PJ, Barrows HS. Issues of generality in medical problem solving. In: Schmidt HG, De Volder ML (eds). Tutorials in Problem-based Learning: A New Direction in Teaching the Health Professions. Assen, The Netherlands: Van Gorcum, 1984.

2. Elstein AS, Shulman LS, Sprafka SA. Medical Problem Solving: An Analysis of **Clinical Reasoning**. Cambridge, MA: Harvard University Press, 1978.

3. Gilhooly KS. Cognitive psychology and medical diagnosis. applied cognitive psychology.1990; 4:261 -72.

4. Marzano RJ, Brandt RS, Hughes CS, et al. Dimensions of Thinking: A Framework for Curriculum and Instruction. Alexandria, VA: Association for Supervision and Curriculum Development,1988 .

5. Barrows HS, Feightner JW, Neufeld VR, Norman GR. Analysis of the **Clinical** Methods of Medical Students and Physicians. Final Report, Ontario Department of Health, Grants (ODH-PR-273 and ODH-DM-226). Hamilton, Ontario,

Canada: McMaster University, 1978.

6. Barrows HS, Norman GR, Neufeld VR, Feightner JW. The **Clinical Reasoning** of Randomly Selected Physicians in General Medical Practice.Clin Invest Med. 1982;5:49 -55.[Medline]

7. Feltovich PJ, Johnson PE, Moller JH, Swanson DB. LCS: the role and development of medical knowledge in diagnosis expertise. In: Clancey WJ, Shortliffe EH (eds). Readings in Medical Artificial Intelligence: The First Decade. Reading, MA: Addison-Wesley, 1984:275 -319.

8. Kassirer JP, Gorry GA. **Clinical** problem solving: a behavioral analysis. Ann Intern Med.1978; 89:245 -55.[Medline]

9. Balla JI. The Diagnostic Process: A Model for **Clinical** Teachers. Cambridge, U.K.: Cambridge University Press,1985 .

10. Barrows HS. Practice-based Learning: Problem-based Learning Applied to Medical Education. Springfield, IL: Southern Illinois University School of Medicine, 1994.

11. Kassirer JP, Kopelman RI. Learning **Clinical Reasoning**. Baltimore, MD: Williams & Wilkins,1991 .

12. Bordage G, Lemieux M. Semantic structures and diagnostic thinking of experts and novices. Acad Med.1991; 66:S70 -S72.[Medline]

13. Boshuizen HPA, Schmidt HG. On the role of biomedical knowledge in **clinical reasoning** by experts, intermediates and novices. Cogn Sci. 1992;16:153 -84.

14. Gale J, Marsden P. Medical Diagnosis: From Student to Clinician. Oxford, U.K.: Oxford University Press,1983 .

15. Groen GJ, Patel VL. Medical problem solving: some questionable assumptions. Med Educ.1985; 19:95 -100.[Medline]

16. Norman GR, Tugwell P, Feightner JW, Muzzin LJ, Jacoby LL. Knowledge and **clinical** problem soving. Med Educ.1985; 19:344 -536.[Medline]

17. Custers E, Regehr G, Norman GR. Mental representations of medical diagnostic knowledge: a review. Acad Med.1996; 71(10 Suppl):S55 -S61.[Medline]

18. Schacter DL. Memory. In: Posner MI (ed). Foundations of Cognitive Science. Cambridge, MA: A Bradford Book, MIT Press,1989 .

19. Schallert DL. The significance of knowledge: a synthesis of research related to schema theory. In: Otto W, White S (eds). Reading Expository Prose. New York: Academic, 1982:13 -48.

20. Johnson MK, Hasher L. Human learning and memory. Annu Rev Psychol. 1987;38:631 -68.[Medline]

21. Nelson K. Event knowledge and cognitive development. In: Nelson K (ed). Event Knowledge: Structure and Function in Development. Hillsdale, NJ: Lawrence Erlbaum Associates, 1986.

22. Fayol M, Monteil J-M. The notion of script: from general to developmental and social psychology. Eur Bull Cogn Psychol.1988; 8:335 -61.

23. Schmidt HG, Norman GR, Boshuizen HPA. A cognitive perspective on medical expertise: theory and implications. Acad Med.1990; 65:611 -21.[Abstract]

24. Smith EE. Concepts and induction. In: Posner MI (ed).Foundations of Cognitive Science. Cambridge, MA: MIT Press,1989 .

25. Barrows HS, Tamblyn RM. Problem-based Learning: An Approach to Medical Education, Series on Medical Education. New York: Springer Publishing Co, 1980.

26. Barrows HS, Bennett K. The diagnostic (problem solving) skill of the neurologist: experimental studies and their implications for neurological training. Arch Neurol.1972; 26:273 -7.[Medline]

27. Lesgold A, Rubinson H, Feltovich P, et al. Expertise in a complex skill: diagnosing x-ray pictures. In: Chi MTH, Glaser R, Farr MJ (eds).The Nature of Expertise. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.

28. Lesgold A. Context-specific requirements for models of expertise. In: Evans DA, Patel VL (eds). Cognitive Science in Medicine. Cambridge, MA: A

Bradford Book, MIT Press, 1989.

29. Grant J, Marsden P. The structure of memorized knowledge in students and clinicians: an explanation for diagnostic expertise. Med Educ. 1987;21:92 -8.[Medline]

30. Rumelhart DE. Schemata: the building blocs of cognition. In: Spiro RJ, Bruce BC, Brewer WF (eds). Theoretical Issues in Reading Comprehension. Hillsdale, NJ: Lawrence Erlbaum Associates,1980 .

31. Grant J, Marsden P. Primary knowledge, medical education and consultant expertise. Med Educ.1988; 22:173 -9.[Medline]

32. Coughlin LD, Patel VL. Text comprehension and expertise in the domain of medicine. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA,1986 .

33. Bordage G, Lemieux M. Some cognitive characteristics of students with and without diagnostic **reasoning** difficulties. Proceedings of the 21st Annual Conference on Research in Medical Education of the American Association of Medical Colleges, Washington, DC, 1986:171 -6.

34. Bordage G, Lemieux M. Structuralism and medical problem solving.Int Semiotic Spectrum.1987; 7:3 -4.

35. Feltovich PJ. Expertise: reorganizing and refining knowledge for use. Professions Educ Res Notes.1983; 4:5 -9.

36. Patel VL, Evans DA, Groen GJ. Biomedical knowledge and **clinical reasoning**. In: Evans DA, Patel VL (eds). Cognitive Science in Medicine: Biomedical Modeling. Cambridge, MA: MIT Press,1989 .

37. Schmidt HG, Boshuizen HPA, Hobus PPM. Transitory stages in the development of medical expertise: the "intermediate effect" in **clinical** case representation studies. In: Proceedings of the 10th Annual Conference of the Cognitive Science Society. Hillsdale, NJ: Erlbaum, 1988.

38. Kassirer JP. Diagnostic **reasoning**. Ann Intern Med.1989; 110:893 -900.[Medline]

39. Brooks LR, Norman GR, Allen SW. Role of specific similarity in a medical diagnostic task. J Exp Psychol: General.1991; 120:278 -87.[Medline]

40. Patel VL, Groen GJ. Knowledge based solution strategies in medical **reasoning**. Cogn Sci.1986; 10:91 -116.

41. Eva KW, Brooks LR, Norman GR. Is on-line **reasoning** equivalent to post-hoc explaining? Presentation at the 109th Annual Meeting of the Association of American Medical Colleges, New Orleans,1998 .

42. Bordage G, Williams RG. Theory and practice in medical education.Professions Educ Res Q.1992; 14(2):1 -5.

43. Custers E. The Development and Function of Illness Scripts: Studies on the Structure of Medical Diagnostic Knowledge. PhD thesis, University of Maastricht, Maastricht, The Netherlands,1995 .

44. Boshuizen H, Schmidt HG. The development of **clinical reasoning** expertise. In: Higgs J, Jones M (eds). **Clinical Reasoning** in the Health Profession. Oxford, U.K.: Butterworth Heinemann, 1995:24 -32.

45. Kassirer JP. Teaching **clinical** medicine by iterative hypothesis testing: let's preach what we practice. N Engl J Med.1983; 309:921 -3.[Medline]

46. Chamberland M, Des Marchais JE, Charlin B. Carrying PBL into the clerkship: a second reform in the Sherbrooke curriculum. Ann Community-Oriented Educ. 1992;5:235 -47.

47. Tardif J. Pour un enseignement stratégique: l'apport de la psychologie cognitive. Montréal, Quebec, Canada: Les Editions Logiques, 1992.

48. Van der Vleuten CPM. The assessment of professional competence: development, research and practical implications. Adv Health Sci Educ. 1996;1:41 -67.

49. Charlin B, Brailovsky CA, Brazeau-Lamontagne L, Samson L, Leduc C. Script questionnaires: their use for assessment of diagnostic knowledge in radiology. Med Teacher.1998; 20:567 -71.

50. Charlin B, Ray L, Brailovsky C, Van der Vleuten C. How to build a script concordance test to assess the reflective clinician. Submitted to Teach Learn Med. 1999.

51. Coles CR. Elaborated learning in undergraduate medical education.Med Educ. 1990;24:14 -22.[Medline]

52. Bordage G. Elaborated knowledge: a key to successful diagnostic thinking. Acad Med.1994; 69:883 -5.[Medline]

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