REVIEW ARTICLE

MEDICAL EDUCATION

Educational Strategies to Promote Clinical Diagnostic Reasoning

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Introduction

Fifteen years after its publication, this 2006 landmark article continues to bestow knowledge and guidance to both teachers and learners of clinical reasoning. Increased emphasis on reasoning skills in medical education and key research developments prompted our desire to update this information. Therefore, we have annotated this article to address some of these developments:

- *Current research on clinical reasoning that expands theoretical lenses to include sociocultural theories as well as cognitive science. Notably, the personal histories that clinicians and patients bring to each encounter play a significant role in implicit bias.*
- *A greater recognition that diagnosis is co-created by the patient and the diagnostic team, which can include a broad array of health care professionals and an understanding that problem representations activate interactive and continuous analytic and nonanalytic reasoning processes.*
- *A call for clinical teachers to observe learners and provide formative feedback as part of an "educational alliance," whereby a transactional delivery of feedback shifts to a conversation aimed at improving learning.*
- *New resources to help clinical teachers facilitate learning, including emerging innovative technologies.*

Clinical teachers differ from clinicians in a fundamental way. They must simultaneously foster high-quality patient care and assess the clinical skills and reasoning of learners in order to promote their progress toward independence in the clinical setting.[1] Clinical teachers must diagnose both the patient's clinical problem and the learner's ability and skill.

The goal of promoting learners' progress toward independence is evolving to reflect how medicine is practiced and how clinicians use resources — human and material — to guide clinical reasoning. Medical practice now focuses on shared decision making and collaborative practice. Thus, teachers should promote awareness of interdependence among patients, families, and other members of the health care team when reasoning through clinical problems with learners. The goal of this interdependence is to reach the best diagnostic outcome possible, which includes being mindful of how unconscious bias influences clinical reasoning. Interdependence also includes the concept of co-creation of diagnosis and treatment (i.e., shared decision making).

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The first recommendation of the National Academy of Medicine's (NAM) 2015 report, Improving Diagnosis in Health Care, was to improve teamwork in the diagnostic process. A major departure from the classic physician-centered approach, this new team includes the patient, treating clinicians, nurses, pharmacists, physical therapists, radiologists, pathologists, and others.

To assess a learner's diagnostic reasoning strategies effectively, the teacher needs to consider how doctors learn to reason in the clinical environment.[2-4] Medical students in a classroom generally organize medical knowledge according to the structure of the curriculum. For example, if pathophysiology is taught according to organ systems, then the student's knowledge will be similarly organized, and the recall will be triggered by questions related to specific organ systems or other contextual clues. In the clinical setting, the patient's health and care are the focus. Clinical problems may involve many organ systems and may be embedded in the context of the patient's story and questions. Thus, in the clinical setting, the student's recall of basic science knowledge from the classroom is often slow, awkward, or absent. Only after learners make new connections between their knowledge and specific clinical encounters can they also make strong connections between clinical features and the knowledge stored in memory.[5,6] This report focuses on how clinical teachers can facilitate the learning process to help learners make the transition from being diagnostic novices to becoming expert clinicians.

DIAGNOSTIC REASONING

There is a rich ongoing debate about our understanding of the complex process of clinical diagnostic reasoning.[2,3] In this report, some of the basic processes involved in clinical reasoning, as understood according to current knowledge, are translated into practical and specific recommendations for promoting the development of strong diagnostic reasoning skills in learners. The recommendations are illustrated by a clinical case presentation.

This article approached clinical reasoning largely from a cognitive perspective. Early clinical reasoning research demonstrated the importance of adequate case-specific knowledge in diagnosis. However, subsequent scholarship helped broaden our theoretical lenses and showed that contextual factors can

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The Case as Seen by a Novice Resident and an Expert Resident.

Patient's story: My knee hurt me so much last night, I woke up from sleep. It was fine when I went to bed. Now it's swollen. It's the worst pain I've ever had. I've had problems like this before in the same knee, once 9 months ago and once 2 years ago. It doesn't bother me between times.

Novice resident's presentation: My next patient is a 54-year-old white man with knee pain. It started last night. He does not report any trauma. On examination, his vital signs are normal. His knee is swollen, red, and tender to touch. It hurts him a lot when I test his range of motion. He's had this problem twice before.

Expert resident's presentation: My next patient is a 54-year-old white man with a sudden onset of pain in his right knee that awakened him from sleep. He does not report any trauma and was essentially asymptomatic when he went to bed. His history is remarkable for two episodes of similar, severe pain 9 months and 2 years ago. He is pain-free between episodes. He is afebrile today. His knee is swollen, tender to touch, and erythematous.

Teacher's inquiry: What do you think is causing this patient's knee pain?

Novice resident's response: It could be an infection. It could be a new onset of rheumatoid arthritis. It could be Lyme disease. Since he doesn't recall falling, I doubt it's an injury. I don't know whether osteoarthritis ever presents like this, but he does have a history of knee pain.

Expert resident's response: The patient has acute gout. He has had multiple discrete episodes with abrupt onset of extremely severe pain involving a single joint with evidence of inflammation on examination. Before all his episodes, he is asymptomatic. I would have expected gout to affect the first metatarsophalangeal joint, but it can present in the knee. Nothing suggests any ongoing, chronic problem in the knee. I don't see any portal of entry to suggest acute infectious arthritis and he looks quite well for that. His other joints are normal on examination. I doubt that he has a flare-up of osteoarthritis with pseudogout or a systemic, inflammatory arthritis such as rheumatoid arthritis.

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significantly impact diagnostic accuracy, even when clinicians have demonstrated adequate case-specific knowledge. In addition, the application of sociocultural theories to clinical reasoning have led to the understanding that diagnosis is a social activity wherein understanding is developed through interactions among patients, health care professionals, and the environment.

Thus, clinical reasoning is now viewed as a contextually situated and socially mediated activity reflecting unique new theoretical interpretations that focus on reasoning in context and the historical lived experiences that patients, clinicians, and other members of the diagnostic team bring to clinical encounters.

Clinical teachers observe learners gathering information from patients, medical records, imaging studies, results of laboratory tests, and other health care providers. On the basis of their observations, and through the discussion of clinical cases, teachers draw conclusions about the learners' performance, including their reasoning processes.

The role of clinical teachers in supporting learners' effective deliberate practice remains critical. Clinical teachers observe learners and provide formative feedback using several approaches. A wide array of tools are available to assess clinical reasoning with varying advantages and disadvantages by method.

- *Direct observation of learners in the authentic clinical environment is essential. Workplace-based assessments (observational tools frequently constructed to align with entrustable professional activities) can be used to assess moment-in-time clinical reasoning.*
- *Innovations in screen-based simulations of patient encounters present emerging opportunities in prospective assessment of reasoning in a standardized manner and at a large scale, although assessing clinical reasoning in simulation cannot replace observations in authentic clinical settings.*
- *Formative feedback — "no-stakes" feedback for learning — is crucial for learning in clinical settings. An updated approach can be framed as part of an "educational alliance" whereby feedback shifts from a transactional delivery of information to a conversation for improving learning in the context of a supportive educational relationship.*

A hypothetical case provides an example of a conversation involving a patient, two learners with different levels of expertise, and the clinical teacher (see Box). In this case,[7-9] a patient with knee pain makes an urgent visit to an ambulatory care practice. A novice resident (with relatively little experience with this patient's problem, which is gout) and an expert resident (who is familiar with this problem, having seen other patients with gout) each independently interviews the patient, performs an examination, presents the case to the preceptor, and separately discusses the case with the preceptor. As becomes evident, the expert resident has transformed the patient's story into a meaningful clinical problem. The novice resident has also transformed the patient's story, but less elaborately. What the teacher hears from both residents differs substantially from what the patient told them.

The expert resident brought two sets of skills to the encounter with the patient. First, this resident probably formed an early impression — a mental abstraction — of the patient's story. Although possibly unaware of this formulation, the resident's mental abstraction influenced his diagnostic strategy. Guided by his early impression, the resident probably asked a series of questions, and the patient's responses guided both further questioning and the planning of a focused physical examination. The resident's approach involved a search for information that could be used to discriminate among any number of diagnostic explanations of the patient's problem. The novice resident might not have formed a mental abstraction of the case and probably was not sure which questions to pose to the patient.

Second, the expert resident's clinical case presentation was a succinct summary of the findings, providing the teacher with a clinical picture of the patient as seen through the resident's eyes. On the basis of the case presentations by both the expert and the novice residents, the teacher may or may not have had a firm idea of what was wrong with the patient. Rather than offer an opinion, however, the teacher asked the expert resident to reason aloud about the case, thereby providing the teacher with additional clinical information about the patient as well as considerable insight into the resident's clinical reasoning skills. The teacher used the same strategy with the novice resident, and although the result added little information about the patient, the teacher learned something about the novice resident's limited clinical reasoning.

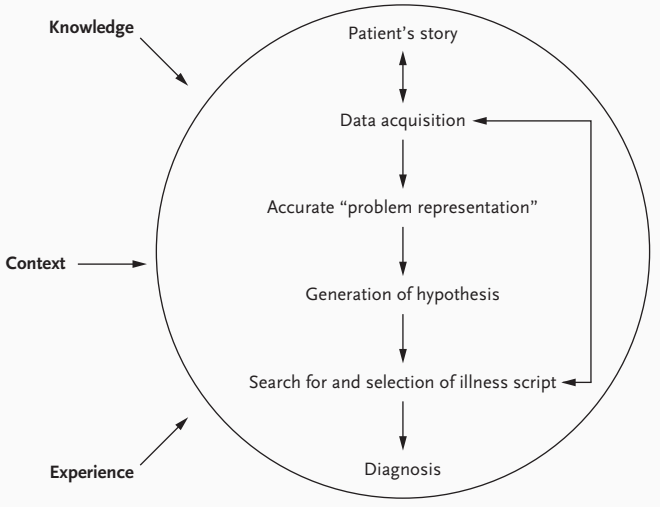

Figure 1. Key Elements of the Clinical Diagnostic Reasoning Process.

Key elements of clinical diagnostic reasoning are shown in Figure 1.

Although Figure 1 portrays diagnostic reasoning as linear for ease of depiction, experts consider it a nonlinear, iterative process in most clinical encounters whereby early problem representation triggers knowledge activation of potential diagnoses and leads to further data gathering, which in turn may alter the problem representation and eliminate some or trigger other diagnostic considerations. When possible, a leading diagnosis is selected, and a management plan instituted.

The diagnostic reasoning process can be considered forward in nature, from data to diagnosis, or backward in nature, from hypothesis to diagnosis (the hypothetico-deductive approach). Some visual diagnoses are made rapidly through pattern recognition.

Since the publication of this article, published problem-solving exercises to illustrate the clinical diagnostic reasoning process have become commonplace. NEJM regularly publishes such exercises in the form of Clinicopathological Conferences (CPCs) and Clinical Problem Solving (CPS) articles.

The first step in diagnostic reasoning, which is based on knowledge, experience, and other important contextual factors,[10] is always data acquisition. Data acquisition, depending on the setting, may include elements of the history, the findings on physical examination, and the results of laboratory testing and imaging studies.

Early in the patient encounter, the problem representation activates a search for a list of possible solutions (i.e., a differential diagnosis) using a combination of fast (pattern recognition) and slow (diagnostic schemas) thinking. As data are obtained, the problem representation becomes more focused, and the differential diagnosis is refined. This iterative process results in the natural evolution of an initial unsolved problem into a refined specific summary statement of the patient's problem with justification for the leading diagnosis and other plausible or "do-not-miss" diagnoses.

To avoid confusion, we distinguish the early problem representation from the summary statement:

- *The problem representation is an abstraction of early key clinical information written or spoken as a problem in the context of generic patient factors (e.g., age, biologic sex, and/or key preexisting diagnoses) and serves the purpose of activating relevant knowledge. The early problem representation evolves during the clinical-reasoning process as hypothesis-driven data bring new information to light.*
- *Once the clinician is satisfied that enough information is known to put forth a probable diagnostic hypothesis, the summary statement is the articulation (verbal or written) of the patient's clinical problem, based on data acquisition and synthesis. The summary statement frames discussion of the leading diagnostic hypotheses (e.g., clinical reasoning argument) during a case presentation.*

Hypothesis generation can occur immediately following acquisition of demographics and the chief complaint. In fact, early consideration of a differential diagnosis may improve diagnostic accuracy among early learners. These initial considerations drive the cyclic nature of information gathering, hypothesis generation, more information gathering (based on the illness scripts activated from memory), and hypotheses refinement. This cycle is shown in Figure 1 with the reverse arrow pointing from search/selection of illness scripts back to data acquisition.

The problem representation is likely important in management reasoning and can lead to activation of management scripts, which are high-level, precompiled, conceptual knowledge structures of the courses of action that a clinician can undertake to address a patient's health care problem(s). Management scripts can be considered as extensions of illness scripts.

Another early step is the creation of the mental abstraction or "problem representation,"[2,8,11] usually as a one-sentence summary defining the specific case in abstract terms. Clinicians may have no conscious awareness of this cognitive step. The problem representation, unless elicited in the teaching setting, is rarely articulated. Rather, the teacher infers the learner's problem representation from the learner's presentation of the case.

For the case used as the example, the expert resident's problem representation, had it been elicited, might have been the following: "The acute onset of a recurrent, painful, monoarticular process in an otherwise healthy middle-aged man." The problem representation illustrates the transformation of patient-specific details into abstract terms. "Last night" became "acute onset," "I've had problems like this before" became "recurrent," "same knee" became "monoarticular," and the patient's age, sex, and medical history are summarized as "otherwise healthy, middle-aged man." In this transformation, the characterization of the problem facilitates the retrieval of pertinent information from memory.[7] The novice resident may be less able than the expert resident to develop an accurate problem representation.

Chunking, the process of taking individual pieces of information and grouping them into larger buckets based on previously acquired knowledge, enables experts to increase the availability of working memory to solve problems. Learners should be encouraged to group or chunk clinical information to enable more-efficient problem synthesis, illness script activation, and discussion of the differential diagnosis. When considered separately, each clinical finding can activate illness scripts independently, resulting in an unwieldy differential diagnosis or list of disconnected possibilities. A succinct problem representation connected to a short list of two or three diagnostic possibilities should be encouraged. This shorter differential diagnosis could give learners more time to explain which discriminating findings lead to the prioritization of the leading diagnosis over other less-likely diagnoses. Generating long lists of possible diagnoses is not associated with diagnostic accuracy.

When prompted by the teacher to reason about the case, the expert resident used abstract semantic qualifiers to describe the case findings. Semantic qualifiers are paired, opposing descriptors that can be used to compare and contrast diagnostic considerations. The resident used several implied pairs when considering hypotheses for a diagnosis of gout: multiple (not single) and discrete (not continuous) episodes, abrupt (not gradual) onset, severe (not mild) pain, and a single joint (not multiple joints). The use of such semantic qualifiers is associated with strong clinical reasoning.[7-9]

To create a concise, appropriate problem representation and to reason succinctly, the resident must have clinical experience with similar patients and must be able to recognize the information that establishes gout as the diagnosis while ruling out other possibilities. The way the clinical experience is stored in memory either facilitates or hinders the ability to formulate the problem representation. Expert clinicians store and recall knowledge as diseases, conditions, or syndromes — "illness scripts" — that are connected to problem representations.[2,4,12,13] These representations trigger clinical memory, permitting the related knowledge to become accessible for reasoning. Knowledge recalled as illness scripts has a predictable structure: the predisposing conditions, the pathophysiological insult, and the clinical consequences (Fig. 2).

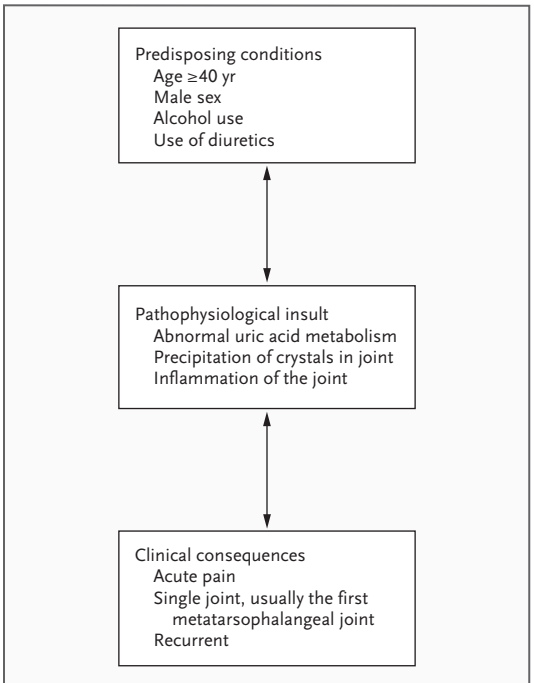

Figure 2. Example of an Illness Script for Gout.

Clinicians store knowledge of specific diseases or syndromes in their memory as illness scripts that work for any variation of the disease or condition under consideration. Illness scripts consist of three components: epidemiological risk factors, pathophysiology, and clinical findings. Some information in the script is core to or a defining feature of the condition and some script elements can accommodate a range of variables. For example, the illness script for gout requires joint involvement (core), but any joint location can be involved such that the diagnosis of gout is not eliminated as a possibility if the first metatarsal phalangeal joint is not involved, even though this is the stereotypical presentation.

As an illness script is triggered, information from the script is compared to information about the event that triggered the script (instantiation) or a representation of a concrete event (i.e., the patient's clinical findings). If important information in the script is missing, the clinician seeks out that information from the patient (or a simulated case). If the patient's clinical findings match with the clinician's illness script, the script is retained for continued consideration.

Teaching using illness scripts may improve the performance of novice learners.

Constructed on the basis of exposure to patients, illness scripts are rich with clinically relevant information. Their content varies for each physician and among physicians. Some illness scripts are conceptual models, such as groups of diseases, whereas others are representational memories of specific syndromes. With experience, clinicians also store memories of individual patients, and the recollection of a particular patient often triggers the recall of relevant knowledge.[14] The defining and discriminating clinical features (Fig. 3) of a disease, condition, or syndrome become "anchor points" in memory. In the future, recollection of such stored experiences expands the clinician's ability to recognize subtle but important variations in similar cases.[13]

When prompted to reason aloud, the novice resident listed possible causes of knee pain. The expert resident, however, compared and contrasted several relevant hypotheses — acute gout, infectious arthritis, osteoarthritis with pseudogout, and rheumatoid arthritis — and included the discriminating features of each possibility. Such reasoning may represent the mental processes of searching for and verifying an illness script, with the elimination of hypotheses for which the defining features of a specific illness script are absent.[2,4,12,13] Such comparisons often take place in the expert clinician's mind during the data-acquisition phase and form the basis of a focused strategy for questioning the patient and for the physical examination. Additional data gathering is purposeful: it is a search for the defining and discriminating features of each illness script under consideration.

Clinicians familiar with the clinical presentation of gout will recognize the pattern of symptoms and signs of gout in the expert resident's case presentation. Such rapid, nonanalytic clinical reasoning is associated with experience with the type of problem, in this case gout. The defining features for a diagnosis of gout are associated in memory as an illness script and, for some clinicians, are also associated with memories of individual patients. Access to these memories is easily triggered when the clinical findings of gout are present. The expert resident recognized the pattern of symptoms and signs of gout and selectively accessed the illness script constructed on the basis of experience.

More recent literature has further explored cognitive load theory and the limitations of working memory in novice and experienced learners. Chunking (grouping individual pieces of information into larger buckets based on previously acquired knowledge) enables experts to expand the availability of working memory to solve problems. Thus, helping learners chunk material can reduce cognitive load. From a teaching perspective, presenting cases to novices at the appropriate level of difficulty and adding scaffolding to help the learner work through the problem may reduce cognitive load and enhance learning.

The novice resident's clinical experience with gout was limited; perhaps knowledge gained from prior cases of gout failed to be transferred to memory. The novice resident used a slower, more deliberate method of testing a hypothesis for this clinical problem, generating multiple plausible hypotheses for acute arthritis. Additional data gathering would be useful either to confirm or to rule out these diagnostic considerations in a conscious, analytic fashion.

Coupling illness script theory with probabilistic reasoning can augment the learner's ability to estimate the likelihood of a diagnosis.

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Evidence suggests that learners with limited experience, and therefore a limited repository of illness scripts from which to draw, might benefit from Bayesian reasoning as a means of building knowledge to think critically. Bayesian reasoning emphasizes the pretest probability of disease based on epidemiologic data and new clinical information (e.g., history, exam findings, or tests) to calculate a revised (posttest) probability. In addition to illness script instruction, evidence suggests that explicit conceptual instruction on Bayesian reasoning significantly improves the accuracy of posttest probability estimation for novice clinicians. This approach will help novices link predisposing factors and clinical data of the illness script with probabilities.

Emerging teaching tools instruct the use of "Bayesian illness scripts" in the diagnostic reasoning process.

Both nonanalytic and analytic reasoning strategies are effective and are used simultaneously, in an interactive fashion.[3] Nonanalytic reasoning, as exemplified by "pattern recognition," is essential to diagnostic expertise,[2-4,6,12,13] and this skill is developed through clinical experience. Deliberative analytic reasoning is the primary strategy when a case is complex or ill defined, the clinical findings are unusual, or the physician has had little clinical experience with the particular disease entity. Clinicians often unconsciously use multiple, combined strategies to solve clinical problems, suggesting a high degree of mental flexibility and adaptability in clinical reasoning.[3,4]

Although some experts in clinical reasoning have proposed that educational strategies to improve clinical diagnostic reasoning focus on cognitive forcing strategies, the impact of such interventions in clinical encounters remains unsubstantiated. Knowledge-based reflection, which encourages learners to carefully analyze the evidence that increases or decreases the probability of diseases in the differential diagnosis, might be effective in some contexts, but data are limited to simulated written cases.

By prompting the learner to reason aloud or eliciting the learner's uncertainties, the clinical teacher can uncover the reasoning process used by the learner. In responses to the teacher's questions "What do you think?" or "What puzzled you?" weak and strong diagnostic reasoning can be readily distinguished.[15] As was true of the novice resident in the case example, learners whose discussion is poorly organized, characterized by long, memorized lists of causes of isolated symptoms, or only weakly connected to information from the case are reasoning poorly.[16] They do not connect stored knowledge with the current clinical case because they lack either experience with such cases or basic knowledge.

Learners with strong diagnostic reasoning skills often use multiple abstract qualifiers to discuss the discriminating features of a clinical case, comparing and contrasting appropriate diagnostic hypotheses and linking each hypothesis to the findings in the case. The discussion between such a learner and the clinical teacher is often quite concise and may be so abbreviated that its result, the diagnosis, appears to be a lucky guess. In such situations, the teacher may need to ask additional questions that probe the learner's reasoning or uncertainties to be sure that reasoning, rather than luck, brought the diagnosis to light. Strong diagnosticians can readily expand on their thinking.[15,16]

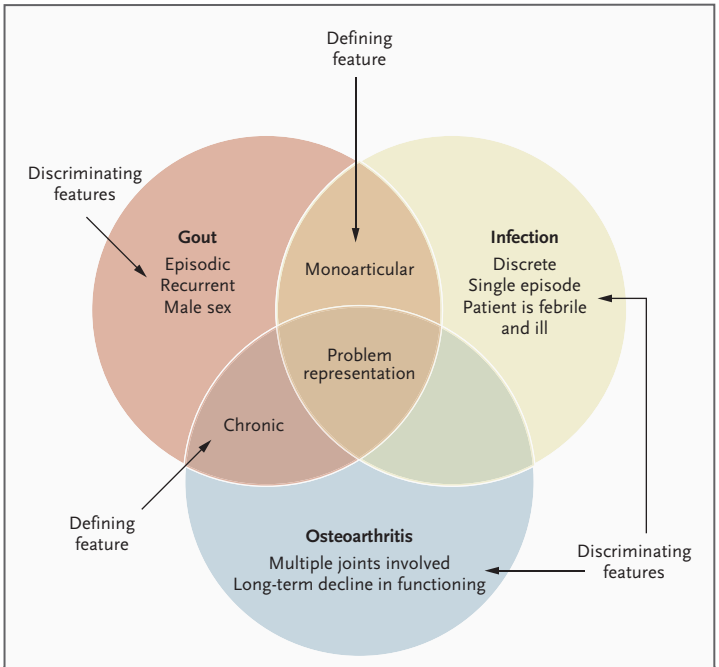

Figure 3. Defining and Discriminating Features of a Set of Diagnostic Hypotheses for Acute Arthritis.

The problem representation is "acute onset of a recurrent, painful, monoarticular process in an otherwise healthy middle-aged man." Defining features are descriptors that are characteristic of the diagnoses (e.g., gout, septic arthritis, osteoarthritis). Discriminating features are descriptors that are useful for distinguishing the diagnoses from one another.

Table 1. Strategies for Diagnosing a Learner's Skills and Addressing Problems in Clinical Reasoning.

Skill	Clue in Case Presentation	Diagnosis	Educational Strategy	Example of Strategy
Data acquisition and reporting	Presentation lacking important information.	Learner has not identified what is important, obtained important information, or both.	Go to the bedside, examination room, or medical record and model the acquisition of important findings; request that the learner revise the presentation accordingly.	"I'd like you to watch me take the history and examine this patient. Look for things I do that are particularly useful in eliciting information. Then let's discuss your observations."
Problem representation	Disorganized presentation, discussion, or both.	Learner has no experience with this clinical problem or lacks a conceptual approach to it.	Go to the bedside, examination room, or medical record and elicit or confirm important findings; think aloud with the learner, linking important findings to your own problem representation.	"Now that we've reviewed the important findings, let's think together about how they point to acute arthritis as the likely problem. I'm considering acute arthritis because. . . ."
	Summary statement only loosely related to the case.	Learner has not identified a problem representation, lacks a coherent understanding of the case, or both.	Instruct the learner regarding the importance of the problem representation; ask for a summary statement (if necessary, compare and contrast it with your own).	"Concise, accurate problem representation is a critical entry point to differential diagnosis. Can you give me a one- or two-sentence summary of this case? Here's how I think it might be put together. . . ."
Generation of hypothesis: Search for and selection of illness script	Multiple diagnoses generated in a random order with no attempt to prioritize them.	Learner has not identified a problem representation or formulated illness scripts for the diagnostic considerations.	Ask the learner to list all important findings from the case, create a problem representation based on selected findings, and prioritize diagnostic considerations that identify discriminating features for each consideration.	"What are the main findings? Can you summarize these in abstract terms in one or two sentences? What are the diagnostic considerations for patients with acute arthritis? Which cause of acute arthritis is most likely to be correct in this case? Why?"
	Discussion of differential diagnosis not linked to findings from the case.	Learner has not formulated illness scripts for the diagnostic considerations or is unable to compare and contrast relevant illness scripts.	Ask the learner to support his or her diagnosis using findings from the case; then ask for at least one additional plausible diagnosis and have learner compare it with alternative diagnostic possibilities. If necessary, provide your own analysis of the case.	"What are your main and alternative diagnoses? What features of the case helped you to discriminate between them?"

Cognitive feedback	Far-fetched diagnosis.	Learner has a poor understanding of the case or lacks a sense of relative probability.	Ask the learner to describe the prototypical presentation for this particular diagnosis, to be followed by a comparison with the findings in this case; identify additional data that would be needed to rule in the diagnosis.	"What is the classic presentation for your diagnosis? What findings in this case fit the typical presentation? Are there enough key features present to continue with this line of reasoning? What else do we need to know about this patient?"
Developmental stage	Presentation or reasoning below the expected level for a common problem.	Learner has not created an "anchor" prototype in memory, has too little experience with this type of problem to create illness scripts, or both.	Ask the learner about his or her experience with this type of case or problem; assign the learner patients who have common problems and prototypical presentations; instruct the learner when reading about the case to compare the primary diagnosis with at least one other consideration, identifying relevant key and discriminating features; and have learner follow up to explain what was learned. Determine whether the learner's difficulty is an isolated or recurring one.	"Have you taken care of other patients with acute arthritis? What do you remember about those patients? I want you to read about the typical presentation of gout and compare it with the typical presentation of infectious arthritis. Identify key and discriminating features for both diagnoses. Tomorrow, tell me what you have learned."
Contextual considerations	Disorganized presentation of a complex and ill-defined clinical problem.	More than one problem representation is possible, there is a risk of premature closure (learner may be making a lucky guess), or both.	Elicit some plausible problem representations; ask the learner to identify and defend primary and secondary diagnoses, using key and discriminating features of the case; articulate your own problem representations and clinical reasoning.	"Tell me how your primary diagnosis is supported by the clinical findings. Choose a reasonable alternative diagnosis and tell me why it does not fit the clinical findings." (Repeat this procedure for each plausible problem representation.)
	Evidence of varying levels of understanding.	Within the group, there is likely to be a broad range of case experience (the stage of training may only partially predict the learner's ability to reason about a case).	Elicit problem representations from two or three other learners present; ask questions to assess each learner's level of expertise; ask more senior learners to reason aloud; articulate your own problem representation and clinical reasoning.	Ask the group: "Does anyone have a different problem representation?" Ask each learner: "What questions do you have about this case?" Ask the senior resident: "Tell us your primary diagnosis and how it is supported by the clinical findings. Did you consider any other diagnosis, and if so, how did you rule it out?"

The responsibility for patients who need more or less specialized care may be transitioned from one clinician to another. These transitions are common in the modern health care system. When transitions interrupt the natural feedback loop on the iterative clinical reasoning process, the opportunity to learn from practice may be lost. Follow-up and feedback may play a role in minimizing diagnostic errors. Some evidence indicates that physicians are motivated to follow up to learn the outcome in the subsequent reasoning process. In fact, follow-up has been described as part of expert diagnostic practice.

Teachers should encourage learners to keep track of and follow-up on patients' outcomes as an important learning strategy to improve clinical diagnostic reasoning.

RECOMMENDATIONS FOR CLINICAL TEACHERS

Clinical teachers can use several strategies to promote the development of strong diagnostic reasoning skills. The recommendations that follow are drawn from research on how doctors reason.[1-4,6,8,9,11-15,17,18] Although experienced clinical teachers will recognize the validity of some of these recommendations, many of the ideas still need empirical testing in the clinical teaching environment.

Viewed in retrospect, the recommendations for clinical teaching described in the original article are especially noteworthy for the integrated focus on knowledge acquisition and the cognitive process of reasoning during deliberate practice. Which of these elements is most critical for learners for the development of effective clinical reasoning remains an ongoing debate. The clinical teaching recommendations highlight the development of robust, accurate illness scripts, which is the core principle of clinical reasoning teaching and learning. Because developing illness scripts for every disease is impossible, teachers should emphasize that learners should focus on the development of robust, accurate illness scripts for typical presentations of common and can't-miss diagnoses in their fields of interest. Through experience, learners will revise these scripts throughout their training.

Researchers have built on the approach of describing learners' patterns of behaviors during clinical reasoning as described in Table 1. These approaches support targeted skills development for learners struggling with diagnostic reasoning.

Experience with patients is essential for establishing new connections in memory between learned material and clinical presentations, for developing illness scripts, and for developing the ability to reason flexibly with the use of analytic reasoning and pattern recognition.[3] As learners listen to patients' stories, learn to transform these stories into case presentations, develop their own illness scripts, and learn to reason about clinical information, teachers can use case-specific instructional strategies to help learners strengthen their skills (Table 1).

ARTICULATING PROBLEM REPRESENTATIONS

Failure to generate an appropriate problem representation can result in the random generation of hypotheses that are based on isolated findings in the case. When the case presentation or discussion is disorganized, the clinical teacher can prompt the learner to create a one-sentence summary of the case with the use of abstract terms.[9] However, teaching learners to articulate problem representations as an isolated teaching strategy is insufficient.[9] Rather, problem representation must be connected to the type of clinical problem — a connection that facilitates the learner's retrieval of pertinent information from memory.

In the teaching environment, several learners with different levels of expertise may be involved in the same case, and eliciting the learners' various problem representations will help the clinical teacher to understand their different perspectives and learning needs. In complex, ill-defined clinical cases, more than one problem representation may need to be considered. The discussion of the different problem representations will help novice learners to appreciate the complexity of the case as well as their own early, limited understanding.

Teachers should articulate their own problem representations to demonstrate the type of abstract summary they seek from learners. Teachers can then reason aloud, linking the summary statement to their own illness scripts and highlighting the discriminating features clinicians seek in the history and physical examination for the consideration of appropriate diagnostic possibilities.[17]

STRATEGIES FOR COMPARING AND CONTRASTING

Novice learners often generate numerous possible diagnoses for any given case. To prioritize such a lengthy list, they should be encouraged to compare and contrast possible diagnoses on the basis of the relationship among the actual clinical data on the case, typical presentations for each diagnostic possibility, and the relative probabilities of different diagnoses.[17,18] Forcing learners to prioritize the list of diagnostic possibilities and explain their justifications helps them to create linkages between the clinical findings in the case and relevant diagnoses, bolstering their ability to develop pertinent illness scripts.

A recent emphasis has been on teaching learners systematic approaches to diagnosing problems (e.g., approach to diagnosing dyspnea). Further study of these systematic approaches is required to determine their efficacy in improving diagnostic accuracy and reducing diagnostic error.

The development of elaborate illness scripts and pattern recognition involves knowledge of the typical presentation of a problem as well as the many atypical presentations or variations on the typical one. It is important for novice learners to begin by creating in memory an anchor prototype of the typical presentation, rather than giving equal consideration to a number of undifferentiated possibilities.[17,19] Early in their training, medical students should be assigned to evaluate patients with common problems — ideally, problems for which there are prototypical presentations. After the features of the prototype have been solidified in memory, additional clinical exposure to similar problems can offer a basis for comparison with the prototypical case, providing learners with an appreciation of atypical or subtle findings.[18,19]

Illness script knowledge should include a general sense of the following:

1. *the base rates of diseases (e.g., in adult patients presenting with dyspnea, the most common causes include asthma, chronic obstructive pulmonary disease [COPD], pneumonia, and heart failure)*
2. *the value of clinical findings (e.g., D-dimer is useful for ruling out pulmonary embolism [PE] in a patient with a low probability of disease, but not helpful in ruling out PE in other patients)*

Teaching basic principles of Bayesian reasoning can inform the traditional intuitive and analytic diagnostic reasoning that most clinicians use. Emerging tools instruct the explicit use of "Bayesian illness scripts" during deliberate practice. Further study is required to determine the efficacy of such tools in improving clinical reasoning.

VARYING EXPECTATIONS ACCORDING TO DEVELOPMENTAL LEVEL

The teacher's expectation of evidence of strong reasoning should vary according to the stage of training of the learner, but the learner's developmental level is often related more to the extent of clinical experience with the case at hand than to the year of training.

For effective teaching, meeting learners where they are, or applying specific techniques that target the learner's level of clinical experience, is essential.

First-year residents, for example, may have clinical reasoning skills that are as advanced as those of senior residents when it comes to common clinical problems that they saw frequently as medical students.[20] Thus, although the stage of training is somewhat helpful to the teacher in determining expectations of and roles for learners, specific questioning strategies are necessary to probe the understanding and elicit the uncertainties of learners at any level.[15] Several different strategies can be used, but open-ended questions are especially useful for assessing the learner's clinical reasoning ability.[21,22] Using this or other similar frameworks, clinical teachers can evaluate a learner's performance on the basis of the expected performance at different developmental levels.

PROVIDING COGNITIVE FEEDBACK

The clinical teacher should provide the learner with specific cognitive feedback.

A qualitative study that examined clinician-educators during medicine rounds identified the following four strategies for cultivating clinical reasoning:

- *emphasizing organization and prioritization*
- *accessing prior knowledge*
- *thinking aloud*
- *analyzing the literature*

The teacher should point out diagnostically meaningful information in the data on the case, identify redundant or irrelevant findings, and highlight the discriminating features, including their relative weight or importance for drawing conclusions as to the correct diagnosis.[17] When a learner suggests a possible but not plausible diagnostic consideration, the teacher can ask the learner to describe the key features of a prototypical case and then to compare the prototype with the findings in the case at hand.[16]

ENCOURAGING USEFUL READING HABITS

Learners should be encouraged to read about their patients' problems in a way that promotes diagnostic reasoning, rather than to read about topics in a rote-memorization fashion, without context.

Knowledge remains essential, but not sufficient, for effective diagnostic reasoning. The role of context cannot be overstated.

The organization of knowledge stored in memory facilitates the recall of key concepts for application to the next relevant clinical case.[5] To enhance their organization of knowledge and their understanding, novice learners should read about at least two diagnostic hypotheses at the same time (e.g., gout and infectious arthritis), comparing and contrasting the similarities and discriminating features. Clinical teachers should encourage reading that promotes conceptualization rather than memorization and provides learners with an opportunity to share what they have learned, testing what has been understood well enough to be explained[19] and reinforcing the importance of self-directed learning.

Some medical textbooks are better organized than others to encourage learning by comparing and contrasting diagnostic considerations.[23] The judicious use of the original literature, even by novices, can be an effective clinical learning tool, especially when it provides important new organizing principles or pathophysiological insights that have yet to permeate textbooks. Learners should be encouraged to identify progressively broader and more complex issues, explore them more deeply, and apply the principles of evidence-based medicine in arriving at answers.

Teachers should also promote awareness of the characteristics of clinical expertise and its development; breaking down the path to expertise into more explicit steps can help learners understand how to improve their diagnostic reasoning performance.

Acquiring diagnostic reasoning expertise requires practice with many cases in many contexts. Deliberate practice in simulation settings is one approach. Maximizing quality of clinical experiences requires learners to reflect on their performance to identify gaps in their knowledge and diagnostic skills and develop goals and strategies to fill the gaps. Learners should select clinical experiences that enable them to improve their areas of diagnostic weaknesses. Because actual practice is limited by the opportunity and randomness of clinical encounters, learners could supplement experiences with clinical problem-solving exercises provided in many journals, applications, and podcasts, focusing on their areas of diagnostic weakness.

In summary, clinical teachers can promote the development of diagnostic reasoning while simultaneously diagnosing both the patient's disorder and the learner's abilities. To do so, however, they must have an appreciation of clinical learning theory and practice and an accurate understanding of the clinical problem in question. Such an undertaking requires that the teacher accompany the learner to the bedside or examination room and perform an independent assessment of the patient and, at the same time, assess the developmental stage and clinical reasoning ability of the learner. Ensuring the quality of patient care and modeling professionalism while promoting diagnostic reasoning skills constitute the true art of clinical teaching.

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