How to improve the teaching of clinical reasoning: a narrative review and a proposal

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CONTEXT The development of clinical reasoning (CR) in students has traditionally been left to clinical rotations, which, however, often offer limited practice and suboptimal supervision. Medical schools begin to address these limitations by organising pre-clinical CR courses. The purpose of this paper is to review the variety of approaches employed in the teaching of CR and to present a proposal to improve these practices.

METHODS We conducted a narrative review of the literature on teaching CR. To that end, we searched PubMed and Web of Science for papers published until June 2014. Additional publications were identified in the references cited in the initial papers. We used theoretical considerations to characterise approaches and noted empirical findings, when available.

RESULTS Of the 48 reviewed papers, only 24 reported empirical findings. The approaches to teaching CR were shown to vary on two dimensions. The first pertains to the way the case information is presented. The case is either unfolded to students gradually – the 'serial-cue' approach – or is presented in a 'whole-case' format. The second dimension concerns the purpose of the exercise: is its aim to help students acquire or apply knowledge, or is its purpose to teach students a way of thinking? The most prevalent approach is the serial-cue approach, perhaps because it tries to directly simulate the diagnostic activities of doctors. Evidence supporting its effectiveness is, however, lacking. There is some empirical evidence that whole-case, knowledge-oriented approaches contribute to the improvement of students' CR. However, thinking process-oriented approaches were shown to be largely ineffective.

CONCLUSIONS Based on research on how expertise develops in medicine, we argue that students in different phases of their training may benefit from different approaches to the teaching of CR.

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INTRODUCTION

Helping medical students to become able diagnosticians is perhaps the most important objective of medical education. However, the solving of diagnostic problems is a challenging task. It is difficult to decide among a large number of conceivable diseases given a limited number of complaints, which often show considerable overlap among diseases. For instance, is pain in the chest a symptom of a cardiac or a pulmonary problem? Does it signify a myocardial infarct, a pulmonary embolism, or an oesophageal spasm?

Contextual circumstances influencing the outcome of a clinical encounter make the diagnostic task even more complicated. For example, research on availability bias suggests that a doctor's diagnoses are likely to become less accurate if the doctor has previously seen a patient with superficially similar symptoms.[1] In addition, features of patients not directly relevant to the diagnosis may lead physicians astray.[2,3] Finally, doctors, like other human beings, need a point of view from which to depart when dealing with a patient. Hypotheses appearing early in the encounter play that role. However, these hypotheses may blind the doctor to alternative, and perhaps more appropriate, explanations for the patient's symptoms.[4]

The acquisition of the aptitude to reason clinically is traditionally left to clinical rotations. On the ward, students see their first real patients and are required to apply their knowledge of disease to these patients for the first time. Learning during rotations is, however, largely a process of learning by doing, and opportunities to critically review one's own performance are limited. Supervision is of variable quality and feedback is irregular and not always consistent. Further, it is not helpful that the number and variety of patients available for practice are often limited.[5] A large study of clinical settings in which clerkships take place showed that fewer than half of students saw any patients with the medical problems that have the highest prevalence rates. Only 6% of students encountered, for example, a patient with a peptic ulcer during internal medicine clerkships.[6]

It will therefore come as no surprise that medical schools have responded to this unsatisfactory state of affairs by beginning to develop clinical reasoning (CR) *courses* that provide students with ample opportunities to practise and take care of their supervision and feedback needs. Typically, these courses are part of the pre-clinical curriculum. Often they are considered as direct preparation for rotations, but they also occur in earlier phases of the curriculum, including in the first year.

The existing literature presents a variety of approaches to the teaching of CR. We will explore this variety in a systematic fashion. The reader will discover that these approaches differ from one another on a number of dimensions. For instance, some favour the use of clinical problems in which information is gradually unfolded, whereas others provide students with complete clinical cases. Some try to teach students how to reason, whereas others favour the application of knowledge. Readers who expect a review of *empirical* findings will be disappointed; there is not yet sufficient research available to help us decide between approaches. Our review, therefore, must be largely narrative in nature.

The different types of instructional tactics described in the next paragraphs seem to assume that 'anything goes'. Which approach is selected by a teacher appears to represent an issue of taste rather than necessity. In the discussion section of this paper we will, however, argue that medical students at different levels of intellectual development wrestle with different informational problems, and therefore may need instructional support adapted to their particular level. Hence, our description of the various ways of teaching CR will culminate in a proposal to take into account the different levels of expertise of medical students when designing a CR course.

Types of tactics employed when teaching CR

In the following section, we will summarise our findings on the various tactics employed in the teaching of CR and briefly discuss our system of categorising them.

METHODS

To identify the approaches employed to teach CR to medical students and in-training physicians, a literature search within the PubMed and Web of Science databases was conducted in June 2014. The search used the terms 'teaching' and 'clinical reasoning', 'differential diagnosis', 'diagnostic reasoning', 'medical decision', 'medical students', 'doctors' and 'physicians', combined into the following query: 'teach* AND [('clinical reasoning' OR 'differential diagnos*' OR 'medical decision*' OR 'diagnostic reasoning') AND ('medical students' OR 'doctors' OR 'physicians')]. Papers published until the date of the review that contained this query in the title or the abstract were selected. We limited our search to publications indexed as articles, proceedings papers or reviews. This strategy yielded 202 publications. First, we read the abstracts and excluded articles that did not present an approach to the teaching of CR but, rather, dealt with the assessment of CR or other aspects of clinical teaching. This resulted in a set of 44 articles. Subsequently, we reviewed the references of the publications yielded by the search to identify additional relevant articles (four articles), which resulted in a total of 48 papers to be included in the review.

We decided to categorise these articles based on two theoretical considerations. The first was a consideration based on cognitive load theory.[7] This theory claims that students solving problems in their domain are better supported when all relevant information is presented to them in full, decreasing load on working memory. Based on this idea, we assumed that it would be meaningful to distinguish between approaches in which case information is presented to students in a sequential fashion (the 'serial-cue' approach) and those in which all information about a patient is presented at once and remains available throughout the diagnostic process (the 'whole-case' approach). The second consideration was based on a fundamental divide in the CR literature. Some suggest that the hallmark of learning to reason clinically is represented by learning of the thinking processes by which expert diagnosticians solve diagnostic problems, for instance hypothetico-deduction,[8] or by following a heuristic or analytical approach.[9] Others claim that CR is a largely knowledge-based activity.[10,11] Processes of reasoning are in the latter perspective ephemeral to the nature and the amount of knowledge and experience involved in successful diagnosis. This distinction was applied to the papers selected: papers focusing on the processes of CR were distinguished from papers in which the application of knowledge was the purpose of the exercise. Finally, it was deemed useful to subdivide the latter category into approaches aimed at the application of causal – pathophysiological – knowledge in CR, and those aimed at distinguishing diseases based on differences in clinical manifestations (distinguishing between 'lookalike' diseases). These distinctions led to a matrix of possibilities as displayed in Table 1. The formats by which patient information is presented (in serial cues versus the whole case) is represented in the rows in the matrix, and the purpose of the exercise (knowledge-oriented versus process-oriented) is represented in the columns. We then classified the articles using this two-way matrix. The first 20 articles, listed alphabetically, were categorised by each of the authors independently, resulting in inter-rater agreement of 95%. This was considered sufficient to enable the second author to categorise the remaining articles on her own. A number of articles presented mixed approaches or were otherwise not easily represented within our categorisation. These were therefore classified separately. Empirical findings, when available, were noted. Finally, 10 papers were theoretical in nature, in the sense that they did not discuss a particular instructional method but reviewed literature on medical expertise development and its implications for the teaching of CR.[10,12–20] They were not categorised.

RESULTS

Of the 48 papers reviewed, 24 reported on empirical studies in which a particular approach was examined.[21–44] Fourteen articles were descriptive in nature, offering only a portrayal of a particular approach to the teaching of CR.[45–58]

The majority (n = 19) of the empirical papers reported on studies that involved an educational intervention delivered across extended curriculum time or during a one-session learning phase, followed by an immediate and/or delayed assessment of students' performance in diagnosing clinical cases. The primary learning resources in these educational interventions were clinical cases. The ways in which these clinical cases were offered varied considerably. Some investigators presented cases in written form, others through simulated or real patients. Students studied these cases individually or in small groups, as classroom activities or in clinical settings. We considered these differences interesting but not consequential for the purposes of the present paper, as we will elucidate. More important are, in our view, the two other aspects of the CR teaching enterprise: the way in which the clinical information in the case used as a starting point for learning is unfolded to students (as serial cues versus as the whole case) and the *purpose* of the exercise (knowledge-oriented versus thinking process-oriented).

Serial-cue approach

In terms of the way in which clinical problems are presented, the most prevalent approach to the teaching of CR encountered in the literature is the serial-cue

Table 1 *Studies reviewed according to the purpose of the teaching strategy and the format in which the clinical problem is presented to students*

	Purpose of the teaching approach			
Mode of presentation of clinical problem	**Knowledge-oriented: causal mechanisms of disease**	**Knowledge-oriented: distinction between lookalike diseases**	**Process-oriented**	**Unclear or mixed**
Serial cues		Kopp *et al.*[42]; Kopp *et al.*[43]	Bacchus *et al.*[21]; Beullens *et al.*[24]; Chamberland[45]; Chamberland *et al.*[44]; Curry & Makoul[46]; Custers *et al.*[52]; Dequeker & Jaspaert[51]; Fuks *et al.*[57]; Goss[47]; Kassirer[48]; Linn *et al.*[49]; Rogers *et al.*[40]; Struyf *et al.*[25]	Hill[55]; Littlefield *et al.*[22]; Pinnock *et al.*[58]; Windish[50]; Windish *et al.*[23]; Nendaz *et al.*[35]
Whole case	Chamberland *et al.*[30]; Chamberland *et al.*[31]; Sacher & Detsky[54]	Lee *et al.*[38]; Fleming *et al.*[53]; Mamede *et al.*[36]; Mamede *et al.*[37]; Papa *et al.*[39]	Bye *et al.*[33]	Allen *et al.*[32]; Montaldo & Herskovic[34]; Nendaz *et al.*[35]
Unclear, mixed or not applicable		Ark *et al.*[29]*; Hatala *et al.*[41]*	Ark *et al.*[28] *; Gay *et al.*[56]; Eva *et al.*[27] *; Round[26]	

* Studies using electrocardiograms as learning material

method. In this approach, the information necessary to diagnose the case is presented to students in a serial fashion. It usually starts with the provision of a chief complaint. Given this chief complaint and the hypotheses that arise from it, students gather the information required to make a diagnosis. The serial-cue method was described in 21 of the 48 papers reviewed.[21–25,35,40,42–52,55,57,58] Basically, the serial-cue method simulates a real clinical encounter, in which students 'play the doctor' and are requested to actively gather the information necessary to arrive at a diagnosis. Students may be asked to extract information either directly from real,[47,49,52] virtual[58] or simulated[22] patients, sometimes played by peers,[23,50] or from a case presenter.[48,51] Students progress step by step, from history taking to requesting diagnostic tests, and findings are unfolded in response to their information requests. As they do so, students may be asked to explain why they have requested that clinical information, and how it would help narrow the differential diagnosis.[21,47,49] A teacher may interact with the students, either while they are gathering clinical information,[23,48,49] or in subsequent feedback sessions,[47] to comment on the students' questions and responses.

Only 10 of the 21 papers describing the serial-cue method reported empirical findings.[21–25,35,40,42–44] Three of these papers used the serial-cue method primarily with the goal of developing students' reasoning processes[24,25,40] and will be discussed in the section on process-oriented teaching approaches. Three empirical studies explored the effectiveness of the approach in fostering students' diagnostic performance, but in only two of them were the findings derived from a randomised experiment in which the impact of the approach to the teaching of CR on students' learning was evaluated by assessing their diagnostic performance on new cases.[22,23] Both studies compared the performance of students who diagnosed cases in the serial-cue format against that of a control group that had not been exposed to any intervention. The findings were disappointing, at least regarding gains in diagnostic accuracy. Despite the additional practice provided to the students who participated in the CR teaching approach, the quality of their differential diagnosis was similar to that of the control group.[22,23] Three other experiments said little about the value of the serial-cue method *per se* because it was applied in both the experimental and control groups as the studies concerned the influence of a decision support system on performance,[21] or of elaborate feedback in worked examples.[42,43]

Finally, one experiment involving the serial-cue method compared the diagnostic accuracy of physicians, residents and students when the clinical problem was presented in a serial-cue format as opposed to a whole-case format.[35] Diagnostic accuracy was significantly lower on the serial-cue format problem in all levels of expertise, but particularly in students. The proportion of students who elicited the correct diagnosis when cases were presented in a serial-cue format was 72% lower than when a complete vignette format was used. According to the authors, the inferior diagnostic performance resulted from failure to collect critical information.[35]

The little research available is certainly insufficient to derive conclusions on the effectiveness of the serial-cue approach. Why might such an approach, which presently lacks empirical support, prevail among clinical teachers? The serial-cue approach may have high face validity because it simulates a real clinical encounter. The actual diagnostic process requires the physician to determine which information additional to the chief complaint is needed for the differential diagnosis. Teachers may tend to believe that the serial-cue approach would therefore better prepare students for what they will have to do in real practice. However, this apparent advantage may hide drawbacks. The approach is quite teacher-intensive because it requires the provision of individualised information and feedback. More important, the possibility that it hinders rather than fosters learning should be considered. In real clinical encounters, physicians search for additional information that helps them confirm (or refute) one or a few initial hypotheses on the patient's problem. For the physician, these hypotheses come to mind because cues in the patient's history activate 'illness scripts' from the physician's memory, or mental representations of a typical patient with a particular disease.[59] These scripts contain findings that are expected to be present in patients with that disease and guide physicians in determining which information needs to be gathered through history taking, physical examination or diagnostic tests. Students do not yet have well-developed illness scripts, especially if they are in the first years of training, and their process of deciding what must be asked from the patient may become, to a large extent, a process of trial and error that places high demands on working memory and may turn out to be overwhelming, possibly hindering learning.[7] The findings from the aforementioned experiment by Nendaz *et al.*[35] suggest that this may indeed happen. Students in particular were handicapped by the serial-cue approach. In Nendaz *et al.*'s[35] experiment, however, the measure of diagnostic accuracy was based on the problem at hand rather than on one or more new problems presented after the intervention. How the serial-cue and the whole-case formats would affect longer-term learning is therefore unclear. What seems clear, however, is that students struggle to determine which information is most useful to test their hypotheses. Whether this is, in the longer run, detrimental or, alternatively, beneficial to learning remains to be determined.

Whole-case approach

In 12 of the 48 papers reviewed, the approach taken to the teaching of CR involved having students diagnose clinical cases, the descriptions of which already contained all the patient's essential features.[30–39,53,54] (Nendaz *et al.*'s study[35] is included here because it investigated both the serial-cue and whole-case formats.)

The descriptive paper by Sacher and Detsky[54] proposes a model for CR teaching sessions that exemplifies the whole-case approach. Students are first required to identify 'focal findings' in a clinical case (i.e. findings that expand or narrow diagnostic possibilities) and then to proceed to systematically explore, with the support of a graphic organiser, the differential diagnosis, taking into account the various aetiologies and body systems. Because all the relevant information is available, students are able to go to and fro, pursuing the various possibilities. However, Sacher and Detzky[54] did not test the effects of their approach.

Ten of the 12 studies that used the whole-case approach made an attempt to compare. These studies either evaluated the effectiveness of an educational intervention that used whole cases against some baseline treatment,[30–34,36–39] or compared the serial-cue and whole-case approaches.[35]

Montaldo and Herskovic,[34] for example, presented written scenarios displaying scripts of patients with typical presentations of heart and lung diseases to year 3 medical students in seminars carried out over 6 months. Students who had been randomly selected to participate in the seminars and therefore were exposed to the prototypical cases performed better on a subsequent diagnostic test than their peers, who had attended the same number of hours of conventional bedside teaching.[34] However, the experimental group's gains in diagnostic performance may well have come from the additional exposure to clinical problems rather than from the whole-case approach itself. Moreover, the students' tasks during the seminars were not described, and the study therefore adds little to our understanding of how students' practice with clinical cases should be organised so that they learn more from them. Potentially more useful insights on this are provided by the six experiments that tested a more extensively described educational intervention.[30,31,36–39] These interventions, which used problems in the whole-case format, focused on fostering knowledge acquisition and will therefore be discussed in subsequent sections.

Knowledge-oriented approach aimed at supporting understanding of pathophysiological mechanisms of disease

Three of the reviewed papers described approaches to the teaching of CR that are oriented towards developing knowledge of the underlying mechanisms of diseases.[30,31,54] Two of these papers reported on empirical studies that explored the use of *self-explanation* as an instructional strategy for the teaching of CR.[30,31] Self-explanation, a technique that has been employed in other domains, consists of having students explain to themselves (out loud) to-be-learned materials presented to them.[60] While diagnosing clinical cases, students are required by this process of self-explanation to read the case and to explain to themselves how the findings present in the case may have been produced by underlying pathophysiological mechanisms, how these signs and symptoms relate to one another, and how they relate to the possible diagnoses considered for the case.

Self-explanation was tested in an experiment consisting of a learning phase, in which students diagnosed clinical cases either with or without self-explanation, and an assessment phase, conducted 1 week later, when students diagnosed different cases of the same diseases studied in the learning phase.[30] Compared with students who had not used self-explanation in the learning phase, students who self-explained performed better on the final test. Self-explanation was beneficial even in the absence of any feedback. However, the positive effect of self-explanation showed up only after 1 week and only on cases with which students were less familiar. While self-explaining these less familiar cases, students used more biomedical knowledge than in familiar cases, which suggests that explaining the case in biomedical terms drives better performance on new cases.[31]

These findings are in line with those of other studies that have also shown the value of understanding the pathophysiological mechanisms underlying clinical findings in the recognition of similar diseases in future cases.[17] While self-explaining the mechanisms underlying a patient's symptoms, students may better understand how these symptoms are linked together, which appears to add coherence to a mental representation of the disease and make it easier to recognise in the future.

Knowledge-oriented approach aimed at supporting learning of the distinctions between lookalike diseases

Nine papers,[29,36–39,41–43,53] eight of which presented empirical findings, described approaches to the teaching of CR that focus on increasing students' ability to distinguish between diseases that share similar clinical presentations. Briefly, these approaches consist of having students practise with clinical cases that portray patients whose presentations look alike by comparing and contrasting the clinical findings of the alternative diagnoses for each case. All but two[42,43] empirical studies compared this approach to the teaching of CR with more conventional teaching methods in terms of their effectiveness to foster students' learning of clinical diagnosis.

An example may illustrate the approach. Two papers[36,37] reported on experiments testing an instructional procedure that encourages reflection in the course of diagnosing internal medicine cases. In this 'deliberate reflection' procedure, students are first requested to provide an initial diagnosis for a case. Subsequently, they are asked to review the case and to identify findings that either corroborate or oppose this first diagnosis. If, as a result of this procedure, they generate alternative diagnoses for the case, students are requested to proceed with the same analysis for all diagnostic hypotheses until they reach a most likely diagnosis. In a first experiment, Year 4 medical students practised with clinical cases, either by using the deliberate reflection procedure, or by providing an immediate diagnosis or by producing a differential diagnosis. Students who followed the deliberate reflection procedure outperformed the other two groups when diagnosing new cases of the same diseases, but the benefits of reflection did not emerge until 1 week later.[36] A follow-up study found deliberate reflection to lead to higher performance, not only on new cases of the diseases studied earlier, but also on adjacent cases, i.e. cases that looked like the cases studied but in fact had different diagnoses. This led the authors to conclude that the deliberate reflection procedure helped students to distinguish more appropriately between diseases that have symptoms in common and are therefore difficult to diagnose.[37]

Two other experiments seem to support the value of approaches to the teaching of CR that are based on reflection and contrastive learning.[38,39] A workshop[38] and a computer-based tutorial,[39] both requesting medical students to contrast alternative diagnoses for clinical cases, fostered learning relative to conventional approaches. However, alternatively, increased exposure to clinical problems *per se* may have caused the experimental groups in both studies to perform better. The benefits of contrastive learning were also demonstrated in teaching electrocardiograph (ECG) interpretation.[29,41] In two experiments, students who practised by comparing examples of ECGs of different diagnoses with one another ('mixed practice') performed better than students who practised with the ECGs grouped according to diagnosis ('blocked practice') on both immediate[41] and delayed[29] post-tests.

Taken together, the findings of these studies provide some evidence for the value of this approach to the teaching of CR in fostering students' diagnostic performance. The process of comparing and contrasting alternative diagnoses while reflecting upon a case seems to enrich mental representations of the diseases examined and possibly also to influence the representations of related but different diseases, making it easier to distinguish them in similar cases in the future.[37] As the positive effects of the approach emerged, in some studies[36,37] even in the absence of any feedback, it became clear that knowledge restructuring apparently takes place regardless of eventual errors in students' reflection upon the cases.

Process-oriented approach: teaching students how to reason

Eighteen papers, 10 of which reported empirical research, focused on students' reasoning *processes* in the teaching of CR.[21,24–28,33,40,44–49,51,52,56,57] These papers were concerned either with teaching students *how to reason* while diagnosing clinical cases,[21,24–26,33,40,44–49,51,52,56,57] or with evaluating the influences of students' modes of reasoning on their diagnostic performance.[27,28] We will first summarise the studies on teaching and subsequently address the second type of study.

Two different types of attempt to teach students how to reason while diagnosing clinical cases were described. The first refers to short courses or seminars on clinical decision making,[26,40] usually addressing topics such as the steps of the problem-solving process (from acquiring information to evaluating hypotheses), Bayes' theorem, decision analysis and clinical algorithms. The second attempt does not focus on decision theories, but aims to teach students a systematic reasoning approach to reaching a diagnosis.[24,25,44–47,51,52,57] Briefly, teaching takes place around clinical cases, which may be either real patients[48,52,56] or cases prepared by teachers for educational purposes and presented to students in written form,[24,25,48] or through video.[51] Usually teaching combines individual or small-group work with interactive sessions. Students work through cases sequentially, from history taking to planning investigations to confirm the diagnosis, and the role of the teacher is to question the rationales behind students' responses, focusing on the hypothetico-deductive reasoning process.

Two of the reviewed papers evaluated whether these interventions aimed at teaching students how to reason translated into gains in students' diagnostic performance. One such study showed that clerks who had and had not attended a course on decision making demonstrated no differences in problem solving according to ratings by clinical supervisors.[40] The results of interventions that teach students how to reason systematically are also disappointing. One study assessed the increase in students' diagnostic ability between the beginning and end of a series of problem-solving clinical seminars.[24] Diagnostic ability was measured using the Diagnostic Thinking Inventory (DTI), a questionnaire consisting of 41 Likert scale-based items. The DTI intends to measure two aspects of diagnostic thinking: the degree of flexibility in thinking, and the degree of structure of knowledge in memory.[61] Thus, the DTI assesses diagnostic ability not in the context of a particular clinical problem or set of problems, but in general. For instance, students are asked to respond to items subsequent to a stem such as: 'While I am collecting information about a patient…' by indicating their positions on a continuum between a statement that posits '…the various items of information usually seem to group themselves together in my mind' and a statement that says '…I often have difficulty seeing how pieces of information relate to each other'.

The authors showed an increase in the scores obtained in the DTI after the series of seminars over those obtained beforehand.[24] However, Pearson product–moment correlations between DTI scores and scores obtained in a final examination consisting of solving clinical cases, although significant, were quite low (0.19 for the pre-test and 0.17 for the post-test, sharing 3–4% of the variance with actual diagnostic performance). Data on the starting point in the clinical problem-solving examination were not presented, and the study[24] lacked a control group, which makes it difficult to determine whether there was any increase in students' diagnostic performance and, if so, what might have caused it. It may well be that students learned the appropriate responses regarding how they should reason, but this is certainly different from showing that they actually made better diagnoses.

By contrast with the aforementioned papers, two of the 18 studies in this category were not concerned with teaching reasoning processes, but, rather, investigated the influences of students' modes of reasoning on their diagnostic performance while learning to interpret ECGs.[27,28] They were able to show that an instruction requesting novice psychology students to combine 'similarity-based reasoning' (i.e. recognition of similarity between the to-be-diagnosed ECG and those seen immediately before) and analytical reasoning led to higher diagnostic accuracy than did instructions to use each strategy in isolation,[28] and than having students decide by themselves how to approach the ECGs.[27] These findings suggest that a reasoning mode that combines pattern recognition and reflective reasoning, which has been shown to increase physicians' diagnostic accuracy,[62,63] may work for students as well. However, others are more sceptical about the efficacy of such a combined approach.[4,64] In addition, students in these studies diagnosed examples of ECGs following instructions provided by the researchers. Whether the instruction adopted in the training session would foster learning and therefore affect performance when students read new ECGs in the absence of instructions is not known.

To sum up, the scarce empirical studies on approaches that attempt to teach students a specific reasoning process through which they may become better diagnosticians provide only limited evidence of their effectiveness. This should come as no surprise if we consider literature arguing that general reasoning skills do not exist separately from the specialised knowledge necessary to understand and diagnose particular diseases.[65,66] In some accounts of how expertise develops in medicine, general reasoning strategies play no role at all.[10,67]

GENERAL DISCUSSION AND A PROPOSAL TO IMPROVE ON THE EFFECTIVENESS OF THE TEACHING OF CLINICAL REASONING

This review of the literature on the teaching of CR allows for a number of conclusions. The first and perhaps most important is that, given the significance attached to teaching medical students to reason clinically, research is largely lacking. There is a real need for studies that may help us progress in this domain. This is particularly important because the field cannot rely on clerkships or rotations as the breeding ground for this skill. The variety of cases offered to students is simply too limited,[6] and the provision of feedback and coaching too haphazard,[5] to trust the professional environment to provide a solid base for the development of this aptitude. Medical educators need to do more and in a more systematic fashion. The establishment of a CR curriculum as part of undergraduate training is in our view long overdue. Educational innovations such as problem-based learning cannot fill the gap entirely because the numbers of cases presented in such curricula are usually too limited.

A second conclusion is that courses aimed at teaching students the general process of reasoning involved in clinical decision making seem to fail. This is not only because evidence supporting the effectiveness of such courses is lacking, but for theoretical reasons as well: general reasoning strategies do not exist separately from knowledge about a particular disease. It is therefore pointless to teach them in isolation.[65,66]

The third conclusion is that, if the impression flowing from the literature is correct, the direct simulation of professional practice – or the serial-cue approach – is the clinical teacher's favourite tactic for the teaching of CR. We found many papers describing this hypothetico-deductive approach as the method of choice, whereas other approaches receive far less attention in the literature and probably in the everyday practice of medical education. This is understandable because the serial-cue approach clearly has the highest face validity of the approaches discussed here: if we wish to help students acquire CR skills, why not expose them to the real thing? Although the approach initially was used in clinical rotations only – until recently nobody in the pre-clinical curriculum worried much about whether students would need training in CR – medical schools are now beginning to offer courses aimed at helping students to develop this ability early in the medical curriculum. However, there are at least two reasons to be somewhat sceptical about the intuitive appeal of the serial-cue approach. The first is based on research which demonstrates that – in domains other than medicine – whole-case approaches as tools for education are more effective because they decrease cognitive load on working memory.[7] This point of view finds some initial support in the previously discussed study by Nendaz *et al.*,[35] which demonstrated the serial-cue approach to be less effective than the whole-case approach. Thus, exposing students to the real thing may not always be the best way to teach.

A second reason to be sceptical is that *students in different phases of their training may need different kinds of support to follow the path to expertise*. This latter idea deserves further elaboration. We do this based on a previously published review of studies supporting the idea that the development of medical students' expertise progresses through a number of transient stages, each characterised by knowledge structures underlying diagnostic performance that are qualitatively different from those of other stages.[67]

First stage: development in memory of detailed causal knowledge explaining disease in terms of pathophysiological principles

In the course of their early medical training, students rapidly develop mental knowledge structures that can be described as rich, elaborated *causal networks* of concepts and ideas explaining the causes and consequences of disease in terms of general underlying biological or pathophysiological processes. When confronted with a clinical case in this stage of development, students can focus only on isolated signs and symptoms and attempt to relate each of these to the pathophysiological concepts they have learned. This is an effortful process. In addition, as they do not yet recognise patterns of symptoms that fit together, processing is detailed.[68] For instance, when confronted with a drug user who possibly uses contaminated syringes and who shows high fever, exhaustion, high pulse rate and a drop in blood pressure, an intermediate-level student might explain these symptoms in terms of: 'Staphylococci entering the bloodstream via the syringe leading to an immune response. This immune response is responsible for the high fever. The bacteria produce endotoxins causing vasodilatation, causing a drop in blood pressure and perhaps toxic shock.'

Second stage: encapsulation of pathophysiological knowledge

However, through extensive and repeated application of such knowledge and particularly through exposure to patient problems, changes in the knowledge structures of these students occur. Their networks of detailed, causal, pathophysiological knowledge of a disease become *encapsulated* into diagnostic labels or high-level, simplified causal models explaining signs and symptoms. An advanced student might therefore explain the symptoms of the drug user by invoking the clinical concept of *sepsis*. Sepsis encapsulates the more detailed causal explanation that students learn first while trying to understand disease.

To speed up this process of encapsulation, students must be enabled to explicitly practise in explaining signs and symptoms in terms of their pathophysiological sources. The self-explanation method, delineated in the previous paragraphs, seems suited to accomplish just this.[30,31] Because it encourages students to pay attention to the details of how human biology produces disease, it creates coherence among seemingly disparate signs and symptoms. It is well known that causality is the most important of the glues that bind concepts and phenomena together and create strong cognitive structures that survive the vagaries of time and are easily activated when the need arises. For instance, Woods[17] found that those students who had to learn a causal explanation to relate a set of symptoms were more accurate in their diagnosis 1 week later when they were presented with similar but different cases than groups who just learned a diagnosis associated with these symptoms.

Third stage: development of illness scripts

As students begin to practise extensively with actual patients, a second shift occurs. They acquire more knowledge of the conditions under which disease manifests, the so-called 'enabling conditions', and begin to appreciate the variability of the symptoms with which disease presents itself in everyday life. Their encapsulated knowledge is reorganised into narrative structures we refer to as *illness scripts*.[59,69] These illness scripts are cognitive scenarios containing, when activated, relatively little knowledge about the pathophysiological causes of symptoms and complaints (because of encapsulation), but an abundance of clinically relevant information about the enabling conditions of disease, and the variability in the signs and symptoms with which disease presents itself. Of course, initially students' illness scripts are necessarily rudimentary because they can only be enriched by experience.

To develop adequate scripts for particular diseases, students need practice that enables them to compare and contrast adjacent diseases. Adjacent diseases are either different diseases that show considerable overlap in terms of symptoms, such as acute viral hepatitis and choledocolithiasis, or representations of a single disease that manifests in quite different ways, such as the 'silent' myocardial infarction in elderly patients. Learning how to keep them apart calls for an analytical approach that focuses on comparing and contrasting sets of symptoms related to particular diagnoses. It is proposed here that the deliberate reflection strategy is suited for this endeavour.[29,36–38,41,53] Under this strategy, students are explicitly encouraged to compare different diseases in terms of which signs and symptoms in a patient's history fit or do not fit with the proposed diagnosis. In addition, several hypotheses are compared and contrasted simultaneously, leading, as Mamede *et al.*[37] have demonstrated, to a better distinction of adjacent diseases in future diagnostic probes even if these adjacent diseases were not explicitly trained for.

Finally, as illness scripts are sufficiently matured and 'sharpened' by the exercises described above, they should be employed as guides in the independent information gathering of the doctor-to-be. It is here that the serial-cue approach becomes most useful in our view because appropriate illness scripts will already be activated when only limited information about a patient is available and will guide the search for further information from the patient relevant for a diagnosis. When a student has sufficiently complete illness scripts in memory, the search will not be haphazard but rational and will be based on weighing of the evidence in the light of the various illness scripts that are either activated at the beginning of the encounter or triggered by new evidence.

CONCLUSIONS

In this paper we advocate a theory-based approach to the teaching of CR based on our understanding of how the knowledge of disease evolves in the mind of the medical student. We have argued that, at the beginnings of their medical studies, students are necessarily preoccupied with how disease and its associated signs and symptoms are produced by the causal mechanisms that make up human biology. In this phase of their studies, students are best supported by *self-explanation* exercises or similar approaches in which they are encouraged to search for a diagnosis by explaining in detail the signs and symptoms of a case in terms of the underlying pathophysiology. We have reviewed some evidence suggesting that this is indeed an effective strategy, particularly if pathophysiological understanding has not yet entirely developed. If pathophysiological knowledge – through repeated application – has become encapsulated and rudimentary illness scripts emerge in memory, the focus in the teaching of CR could shift to *deliberate reflection* as a tool for learning how to differentiate among various diseases and between the often subtle variations in how disease expresses itself. Such a compare-and-contrast approach has been demonstrated to be superior to simple differential diagnosis in a series of experiments. The serial-cue approach, ubiquitously used in medical education, is in our view useful when students have developed illness scripts that really help them to ask the right questions, to undertake appropriate physical examination, and to order further investigations that are really relevant to the needs of the patient. An approach to the teaching of CR that takes into account the intellectual needs of students and their level of expertise is, in our view, rational and will improve the diagnostic skill of future doctors over and above what is presently feasible in medical education. However, this view requires elaboration and the support of further research in order to become empirical reality.

How might a proposal such as this be tested? The most straightforward way to do this is to directly compare the effects of the serial-cue approach with those of the self-explanation and the deliberate reflection procedures in three groups of students at different levels of development: novices, and intermediate and advanced students. Based on the assumptions outlined herein, we predict that among novices, the self-explanation procedure will lead to better diagnostic performance; among intermediates, the deliberate reflection strategy will outshine the other two, and in advanced students, the serial-cue procedure will be most useful.

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