Clinical reasoning processes : unraveling complexity through graphical representation

CHARLIN, Bernard, *et al.*

Abstract

Clinical reasoning is a core skill in medical practice, but remains notoriously difficult for students to grasp and teachers to nurture. To date, an accepted model that adequately captures the complexity of clinical reasoning processes does not exist. Knowledge-modelling software such as MOT Plus (Modelling using Typified Objects [MOT]) may be exploited to generate models capable of unravelling some of this complexity.

Reference

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Clinical reasoning processes: unravelling complexity through graphical representation

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CONTEXT Clinical reasoning is a core skill in medical practice, but remains notoriously difficult for students to grasp and teachers to nurture. To date, an accepted model that adequately captures the complexity of clinical reasoning processes does not exist. Knowledge-modelling software such as MOT Plus (Modelling using Typified Objects [MOT]) may be exploited to generate models capable of unravelling some of this complexity.

OBJECTIVES This study was designed to create a comprehensive generic model of clinical reasoning processes that is intended for use by teachers and learners, and to provide data on the validity of the model.

METHODS Using a participatory action research method and the established modelling software (MOT Plus), knowledge was extracted and entered into the model by a cognitician in a series of encounters with a group of experienced clinicians over more than 250 contact hours. The model was then refined through an iterative validation process involving the same group of doctors, after which other groups of clinicians were asked to solve a clinical problem involving simulated patients.

RESULTS A hierarchical model depicting the multifaceted processes of clinical reasoning was produced. Validation rounds suggested generalisability across disciplines and situations.

CONCLUSIONS The MOT model of clinical reasoning processes has potentially important applications for use within undergraduate and graduate medical curricula to inform teaching, learning and assessment. Specifically, it could be used to support curricular development because it can help to identify opportune moments for learning specific elements of clinical reasoning. It could also be used to precisely identify and remediate reasoning errors in students, residents and practising doctors with persistent difficulties in clinical reasoning.

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INTRODUCTION

How doctors develop clinical reasoning skills has fascinated researchers in medical education for decades.[1–3] Yet unravelling the complexity of clinical reasoning continues to present a formidable challenge to teachers and learners in medicine. Part of the difficulty stems from the observation that seasoned doctors often reason through cases using rapid, tacit cognitive processes, at least when dealing with common or routine clinical situations.[1,4,5] When asked to render these processes explicit, they typically find it difficult to slow them down and to retrace their cognitive steps[6]. It is therefore often hard for medical trainees to grasp the various dimensions and nuances of their tutors' clinical reasoning processes, and for medical teachers to foster clinical reasoning skills in medical learners. Another challenge routinely facing medical educators is the identification and remediation of specific errors in clinical reasoning.[7–10]

A model capturing the richness and complexity of clinical reasoning processes would therefore be very useful to inform teaching, learning and assessment. Such a model is difficult to create because clinical reasoning depends on mobilising and processing vast networks of knowledge that may not be easily accessible to conscious scrutiny. Early attempts to develop generic models of clinical reasoning, which depicted its processes in a primarily linear fashion, largely fell by the wayside years ago. However, modern methods of concept mapping[11,12] have the potential to reinvigorate the field and prompt significant advances in the establishment of a comprehensive model of clinical reasoning.

Concept maps are graphical tools for organising and representing knowledge.[13,14] Recently, computer software has greatly facilitated the dissemination of concept mapping as a research tool in many domains, including medical education. However, the concept-mapping software in current use provides neither guidance nor constraints, such that users are free to create an infinite array of possible models. Knowledge modelling software that includes grammatical constraints during model construction may allow users to generate maps that are better organised, more complete, more useful in practical settings and more efficient in communicating information than their traditional non-constrained counterparts.[11,12]

The Modelling using Typified Objects (MOT) software and technique is an innovative tool with built-in rules of grammar for guiding modelling.[11] It may be used to map clinical reasoning processes and render knowledge networks and strategies explicit.[11,12] The goals of this study were: (i) to develop a new, comprehensive representational model of clinical reasoning processes using MOT Plus software intended for use by teachers and learners, and (ii) to provide data on the validity of this model.

METHODS

This research was situated in a socio-constructivist paradigm whereby the processes and guide were co-constructed with clinical educators who were involved at each step. We used a qualitative methodology known as participatory action research, a process of development carried out collaboratively by a group of people interested in changing practice in their setting.[15]

MOT software

The MOT software can be described as a semi-structured cognitive mapping tool. It includes a typology of knowledge objects and a typology of links. This software was developed in 1992 by the LICEF (Laboratoire en Informatique Cognitive et Environnements de Formation) Research Center, Montreal, Quebec, Canada.[12] Its current version, MOT Plus 1.6.7, is available in English and French, free of charge, at www.licef.ca (under 'Realisations/ Produits'). It has been used to help design courses, to promote knowledge transfer in corporations, to enhance e-learning courses and to facilitate information management.[11,12]

A MOT model is the graphical expression of a field's knowledge objects and the links that unite them. The grammar of MOT uses geometric symbols to represent types of knowledge objects, such as concepts (rectangles), procedures (ovals) and principles (hexagons). It also defines the types of link that are permissible between the various types of knowledge. There are six types of link: composition (C: 'is composed of'); specialisation (S: 'is a sort of'); instantiation (I: 'is an example or instance of'); precedence (P: 'precedes'); input/product (IP: 'is an input to' or 'produces'), and regulation (R: 'is a regulating principle for'). Using these types of knowledge objects and types of link, the MOT software enables the modelling of any field of knowledge or competence. When a competence or a knowledge field is complex, a model can be expanded into several sub-models.[11,12]

Participants

Six clinician-educators (hereafter referred to as clinician participants [CPs]) were interviewed as a group in a series of sessions occurring over more than 250 contact hours. The participants were selected from different disciplines: four were medical doctors (two in family medicine, one in otolaryngology, one in geriatrics); one was a dentist with expertise in oral and facial pain, and one was a psychologist affiliated with a department of family medicine, who works directly with residents experiencing clinical reasoning difficulties. Three participants were male and three were female. All CPs had > 15 years of clinical experience and were educators with a particular interest in clinical reasoning.

Construction and validation of the model

The process of participatory action research is often described as a spiral consisting of several reflective rounds.[15] Following this methodology, we submitted the MOT model to a three-round validation process. During each round, we solicited critical reflections and comments from the participants, and adjusted the model accordingly. This method therefore enabled us to concurrently construct, amend and validate the model.

Round 1: construction and initial validation

A cognitician, who was familiar with the MOT software and technique, interviewed CPs to 'extract' and analyse their knowledge, reflections on action[16] and cognitive pathways, and subsequently converted them into a graphic representation adhering to the grammatical rules of MOT. Knowledge extraction and graphical construction of the model were integrated and based on multiple successive iterations in 2-hour sessions held over 2 years. A concurrent process of validation occurred during this first stage as the cognitician, who led the discussion, helped CPs to unravel their reasoning processes and identify inconsistencies and gaps in the emerging model. The process was repeated until all participants felt that the model was 'saturated' (i.e. that it provided an adequate depiction of their conscious cognitive pathways during clinical encounters). During sessions, CPs were also encouraged to identify important definitions and concepts from the clinical reasoning literature that they felt were useful for constructing and validating the model.

Round 2: groups of clinician-validators

The model produced at the end of the first round was then submitted to a sample of 12 doctors. The sample was purposeful. To ensure the assembly of a diverse panel, participants were selected based on their interest and experience in medical education and their clinical specialties. Potential participants were given information on the design of the study. The study was approved by the university's institutional review board and all those contacted gave informed consent prior to participation.

During this second round, a printed copy of the MOT model prepared during Round 1 was presented to clinician-validators (CVs). Clarification questions were answered and CVs were then randomly divided into four groups of three participants that were sent into separate rooms. Each group encountered a simulated patient (SP) trained to depict the same clinical scenario involving a chief complaint of chronic fatigue. The simulated situation was chosen because clinicians from all disciplines were felt to be likely to have some familiarity with this common clinical presentation. In each room, one CV volunteered to interview the SP, while the other two CVs observed the interaction, looked at their printed copies of the model and took notes. If the CV conducting the interview requested a specific examination or laboratory result, the SP provided the relevant data. In all rooms, a CP recorded all observable indicators of reasoning (questions, hypotheses generated, signs, investigations, etc.). All encounters were videotaped. When the SP left the room, the video of the encounter was played and the three CVs were given the opportunity to comment on reasoning processes they observed or might have used instead. The goal of this activity was to place CVs in a clinical reasoning situation with the model in hand with which they could compare their own reasoning pathways.

Finally, all 12 CVs returned to a common conference room, where a plenary session was held in which all the models annotated by the CVs were shared. The CVs were instructed to: (i) specify which elements within the model were relevant, erroneous or missing; (ii) determine if the model was congruent with their perceptions of their own clinical reasoning processes; (iii) discuss the strengths, weaknesses and potential missing elements of the model, and (iv) discuss the utility of the model for learning and teaching clinical reasoning. The entire second round of validation took approximately 4 hours to complete.

Round 3: CPs and the cognitician

In this final round of model validation, data obtained in the second round were used by CPs and the cognitician to make final adjustments to the MOT model with the added aim of producing a model that would be detailed enough to reflect the multidimensional structure of clinical reasoning, but would not be prohibitively unwieldy. In other words, CPs were requested to fine-tune the model such that important processes and concepts that emerged in Rounds 1 and 2 were included, but excessive details that might render the model cumbersome or impractical to use as a teaching and learning tool were avoided.

RESULTS

The Modelling using Typified Objects modelling sessions confirmed that clinical reasoning is a highly complex and multifaceted process. The CPs were all seasoned educators, who were well versed in classical clinical reasoning concepts, such as hypothesis generation or hypothetico-deductive reasoning, but in the early stages of modelling they realised that certain concepts required operational definition to ensure a common base of language and understanding among themselves during the construction and validation of the model. Space limitations preclude the inclusion in this paper of all discussed concepts. The following section defines concepts taken from the medical education literature that prompted discussion among CPs and were incorporated within the model.

Concepts

Salient concepts that emerged in the research process concerned diagnosis versus categorisation, types of knowledge used in clinical encounters, semantic transformation of information, problem solving, problem representation and metacognition.

Diagnosis versus categorisation

Cognitive psychologists consider that diagnosis is a categorisation task that consists of placing patients' illnesses in different classes according to their attributes.[2,17,18] Because for a doctor 'the diagnosis' is a precise entity and because the primary function in many medical encounters (such as in emergency medicine) is to understand the situation enough to begin action, such as investigation or treatment, rather than to obtain a precise diagnosis, CPs agreed that 'categorisation for the purpose of action' rather than 'diagnosis' better described the product of initial phases in clinical reasoning.

Types of knowledge used

There is growing agreement among researchers and medical educators that several types of knowledge interact in a medical encounter.[1,4,19,20] The CPs felt it was necessary to specify these in order to produce a model that would be useful for teaching and learning. The illness script theory[18–23] assumes that knowledge networks adapted to clinical tasks develop through experience and operate autonomously beneath the level of conscious awareness. These networks consist of associative links among illnesses and their attributes, consequences, investigation or treatment, and links with memories of previously encountered exemplars of the illness (instances). In ambiguous situations, clinicians search for a fit between the available information and appropriate scripts.[23,24] The CPs reported that, in clinical situations, they effectively mobilise specific knowledge (scripts) relevant to the particular situation (e.g. knowledge related to vertigo and then knowledge linked to cervical masses when they see two successive patients whose main complaints are, respectively, dizziness and progressive swelling of the upper neck). The group reported that clinical reasoning occasionally taps into sources of knowledge of a different nature and that the concept of knowledge encapsulation[20,25] describes that type of knowledge well. In the model, these latter sources of knowledge are referred to as 'biological, psychological and sociological knowledge'.

Semantic transformation, problem solving, problem representation and metacognition

For cognitive psychologists,[26] problem solving involves processes that transform the initial state of the problem into a state in which the goal is achieved. The key to solving a problem is to represent it in such a way that the required processes to understand and solve it can apply.[26] Problem representation has a crucial role in problem solving.[26,27] It was clear to participants that the clinician's representation of a patient's problem changes over the course of the encounter with the discovery of additional data. Semantic transformation emerged as another key concept.[28] Clinicians ascribe meaning to the presenting symptoms and clinical findings by transforming the data using semantic qualifiers that represent conceptualisation or abstraction of the clinical findings. For instance, 'a patient's painful, swollen, right knee that began 2 nights ago with attacks 2 and 9 years ago' is transformed in 'an acute, recurrent attack of abrupt, nocturnal and extremely severe pain in a single, large joint'. Metacognition refers to an individual's knowledge concerning his or her own cognitive processes.[2,29] In medical practice, the application of metacognition implies that the clinician is aware of encounter goals and verifies that his or her cognitive processes and actions are contributing to the achievement of the goals of the clinical encounter.

The MOT model

The MOT model is hierarchical. It is depicted on six screens that show, respectively, a main model and five sub-models. Four screens are presented here. The complete, updated model (with appendices) can be accessed at www.medent.umontreal.ca/clinical-reasoning/. Figure 1 features the main model, a graphical representation of the core clinical reasoning processes that emerged during development of the model. Beginning from the left side of the screen, the concepts (rectangles) 'Context' and 'Patient' are rich input sources for the process (oval) 'Identify early cues'. The product of this process, 'Initial data', then feeds into the process 'Determine the objectives of the encounter'. These objectives orient the process 'Categorise for the purpose of action'. This process has two possible outcomes: 'Categorisation is suitable for purposeful action' and 'Categorisation is NOT suitable for purposeful action'. The former outcome feeds another process, 'Implement purposeful action', which has 'Investigations' and 'Therapeutic interventions' as outputs. Results of these actions are then evaluated. If satisfactory, the *episode of care* is terminated. If not, the categorisation process or the therapeutic interventions put in place are reconsidered.

Within Fig. 1, the core clinical reasoning processes are depicted mainly along the screen's horizontal axis. However, the vertical axis of the figure is also important. Doctors' repertoires of knowledge are represented beneath the series of core processes by rectangles entitled 'Clinical knowledge organised for action (= illness scripts)' and 'Biological, psychological, sociological knowledge'. Links show that the latter underpins the former and that each clinical encounter modifies and enriches illness scripts. Above the series of core processes, problem representation is horizontally depicted by three rectangles designating, respectively, 'Initial representation', 'Dynamic representation' and 'Final representation'.

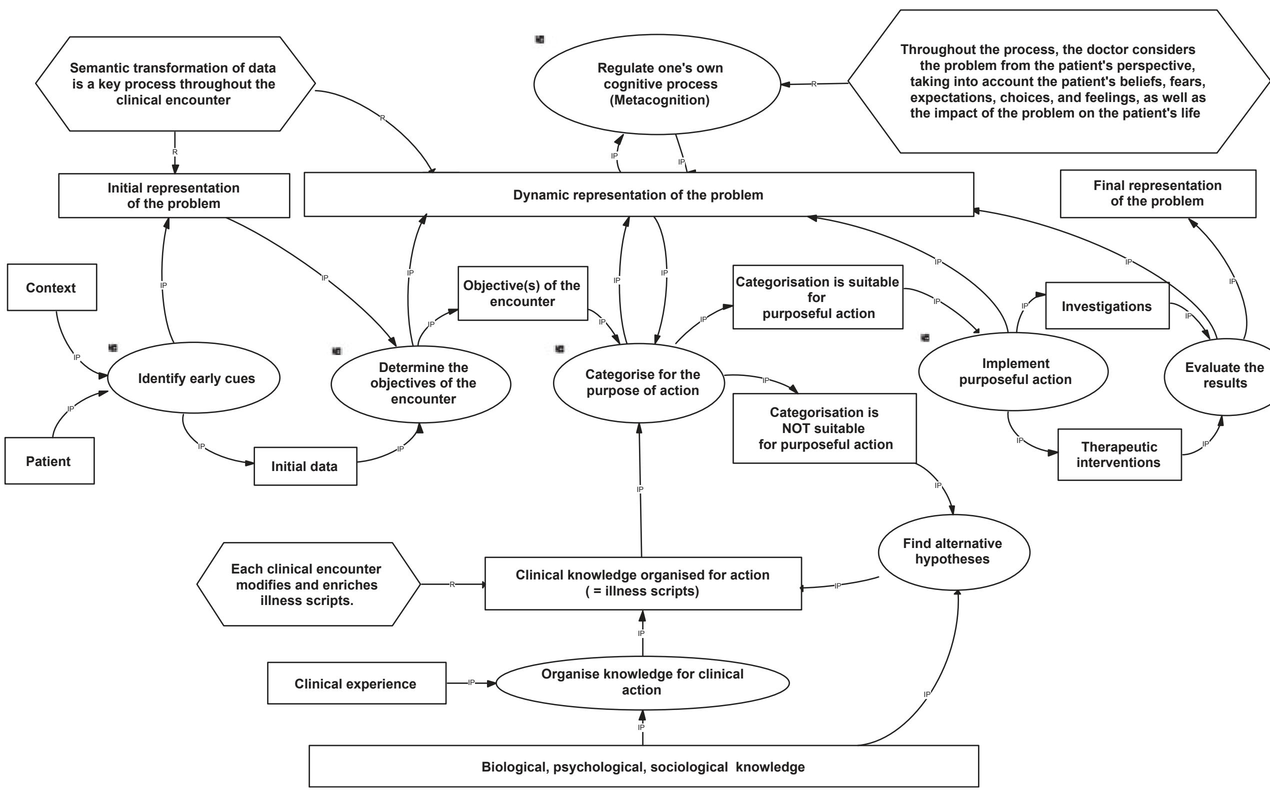

Figure 1 Graphical representation of core clinical reasoning processes; main model

Above all is the metacognition process. A regulating principle, contained in a hexagon, describes the importance during clinical reasoning of taking into account the patient's perspective and the impact of the illness on the patient's life.

On the site (www.medent.umontreal.ca/clinical-reasoning), clicking on red arrows allows the user to navigate between the main model and the five sub-models that depict specific processes from the main model in greater detail. Examples of these sub-screens are shown in Figs 2–4.

Figure 2 depicts the five processes (ovals) that underlie the process 'Determine the objective(s) of the encounter': (i) 'Clarify the patient's request(s)'; (ii) 'Acknowledge the request'; (iii) 'Acknowledge the information'; (iv) 'Identify the patient's needs', and (v) 'Establish priorities'. As shown, 'Patient's request(s)' (input, represented by a rectangle) feeds the process 'Clarify the patient's request(s)', which produces as outcome (another rectangle) the 'Patient's needs according to the patient'. 'Request from the referring doctor' (an input) feeds the process 'Acknowledge the request', which produces as outcome 'Patient's needs according to the referring doctor'. 'Identify the patient's needs' is a process that results in 'Patient's needs according to the doctor'. The four outcomes feed the fifth process, 'Establish priorities', which ultimately produces the 'Objective(s) of the encounter'. This process is regulated by a principle (contained in a hexagon): 'When establishing priorities, factors such as urgency, appropriateness and efficiency must be considered.'

Figure 3 depicts the sub-model 'Categorise for the purpose of action'. This process is informed by patient data and the objectives judged to be relevant in the encounter. It bears upon repertoires of knowledge for action (illness scripts). It is composed of a succession of six sub-processes: (i) 'Search for

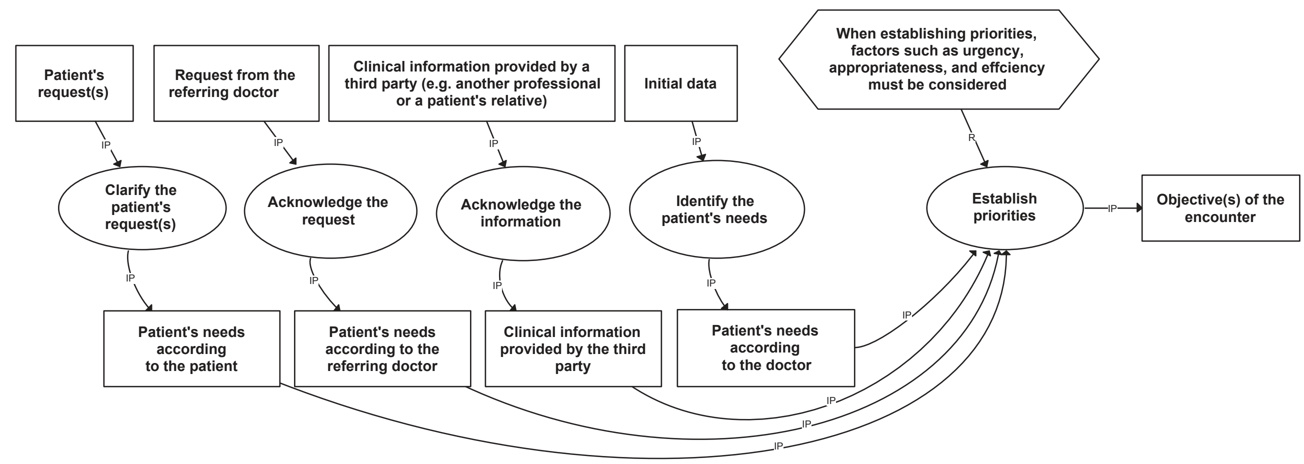

Figure 2 Process: 'Determine the objective(s) of the encounter'

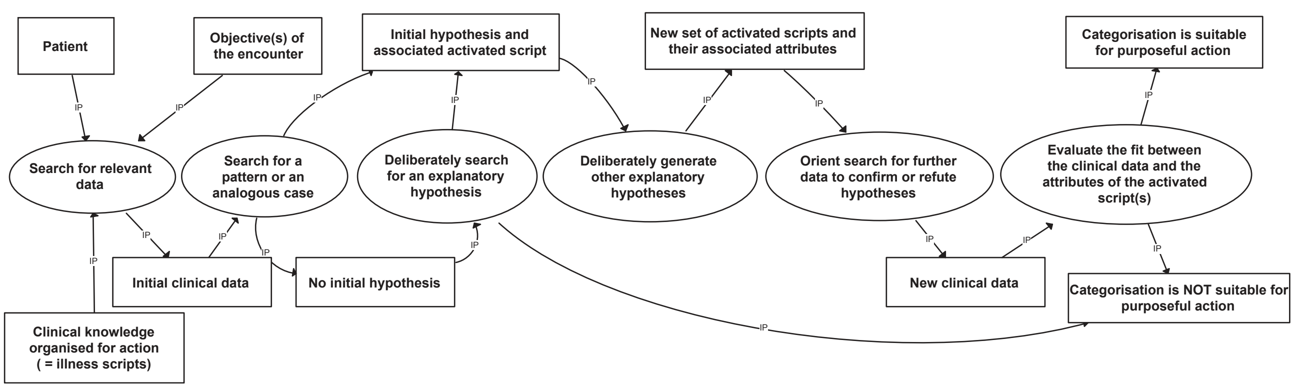

Figure 3 Process: 'Categorise for the purpose of action'

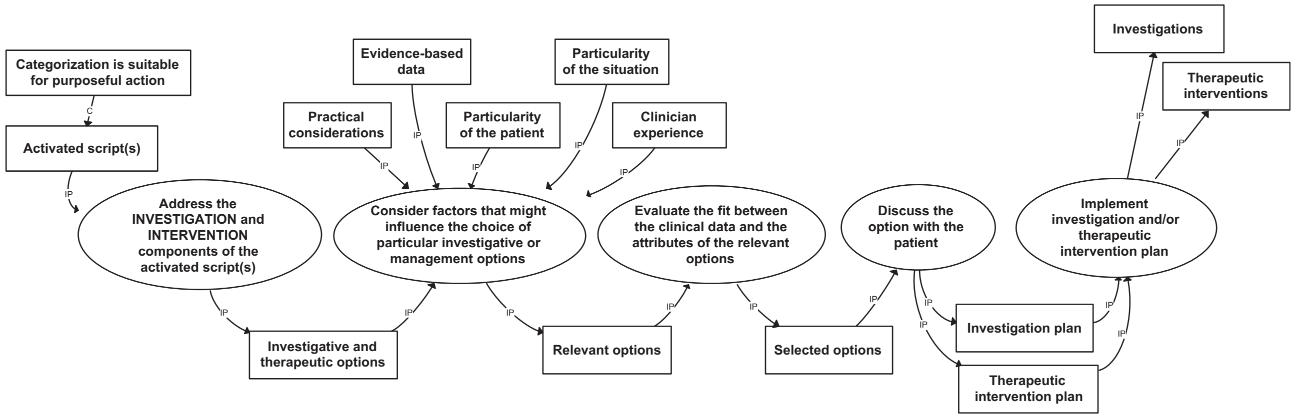

Figure 4 Process: 'Implement purposeful action'

relevant data'; (ii) 'Search for a pattern or an analogous case'; (iii) 'Deliberately search for an explanatory hypothesis' (if there is no initial hypothesis); (iv) 'Deliberately generate other explanatory hypotheses'; (v) 'Orient search for further data to confirm or refute hypotheses', and (vi) 'Evaluate the fit between the clinical data and attributes of the activated scripts'. The activation of hypotheses and their associated scripts gives access to script attributes that inform the oriented search for data to confirm or refute hypotheses. The process 'Categorise for the purpose of action', composed of these six sub-processes, has two possible outcomes: 'Categorisation is suitable for purposeful action' and 'Categorisation is NOT suitable for purposeful action'. Subsequent processes are launched by each of these outputs.

Figure 4 depicts the series of processes that are launched by the output 'Categorisation is suitable for purposeful action'. *Investigation* and *treatment components of selected script*(s) are then activated. Factors that might influence the selection of particular investigative or management options, such as practical considerations (e.g. cost, availability), evidence from the literature, patient profile and preferences, the particularity of the situation, and the clinician's level of experience, are then considered. The myriad possible options are thus narrowed down to several that are relevant to the current case and fit well with the clinical data. These are discussed with the patient, leading to the selection of appropriate actions and producing 'Investigations' and 'Therapeutic interventions' that are then implemented.

The two other sub-models, which describe the processes 'Identify early cues' and 'Regulate cognitive processes', are available online (Figs S1 and S2).

DISCUSSION

Toward a new 'enriched' generic process model of clinical reasoning

The present study represents a modern revival of attempts to model generic clinical reasoning pathways.[3,30–32] Our own model, derived through a computer-generated cognitive mapping methodology, depicts clinical reasoning as a series of highly complex, multidimensional, non-linear processes that depend on the mobilisation of specific knowledge held in long-term memory. Our view is that the MOT model is not at odds with current concepts regarding the quality and content of the knowledge base, or postulated mechanisms such as hypothesis generation or problem representation; in fact, it encompasses them and are necessary elements of the model.

Research has shown that clinicians follow divergent lines of reasoning when solving a problem[33] and that there rarely exists a 'single correct pathway' to a clinical solution. Nevertheless, our study suggests that doctors across different disciplines traverse common cognitive signposts when reasoning through cases in their respective domains. These clinical reasoning signposts, initially identified by our CPs, were subsequently acknowledged and validated within a large array of medical specialties such as neurology, psychiatry and internal medicine, and even dentistry. This indicates that there are common reasoning processes that clinicians across different disciplines routinely employ, and common steps that all seem to be essential for success in problem solving during clinical encounters. We suspect that, depending on the discipline, some processes may be more salient but that the essence of the processes is similar. For instance, categorisation/diagnosis is often central in medicine, whereas in dentistry a greater part of reasoning may revolve around treatment planning.

Lessons drawn from the development of the MOT model

The extraction and graphical representation of the clinical reasoning processes of our participants raised several important points. Firstly, it confirmed the dynamic nature of problem representation[2,27] throughout a clinical encounter. Secondly, CPs found the processes they used when considering management (i.e. investigation and treatment) options very similar to those they employed during categorisation processes: both entailed a search for a fit between activated scripts and information derived during the clinical encounter. For instance, performance of a lumbar puncture (an investigative option) 'fits' with the investigation script 'measure the patient's intracranial pressure' only if there is no clinical evidence of elevated intracranial pressure (such as papilloedema, which might be considered an unacceptable value for the 'measure intracranial pressure' script prior to the acquisition of a computed tomography scan of the head). Thirdly, the core reasoning processes depicted on the horizontal axis of the main screen of the model suggest that, from the moment a clinical encounter begins, a whole series of concomitant cognitive actions occur: the clinical reservoir of knowledge is tapped; scripts are mobilised and enriched, and from time to time encapsulated bio-psycho-social knowledge is accessed. All these processes work in parallel and are under the control of metacognition, indicating that clinical reasoning is not a linear process consisting of a succession of steps, but, rather, a complex deployment of numerous cognitive processes.

Potential educational applications of the MOT model of clinical reasoning

The identification and graphical representation of the complexity of clinical reasoning has potentially important applications for use within undergraduate and graduate medical curricula to inform teaching, learning and assessment. The MOT model could be presented early in these curricula as an advance organiser, thus providing students with an overview of experts' clinical reasoning processes. It could be used to support curricular development because it can help to identify opportune moments for students to learn specific elements of clinical reasoning, and help students gain a global appreciation of clinical reasoning processes even while they concentrate on specific aspects in isolation in dedicated teaching sessions.

Under the complex and ambiguous conditions that characterise daily practice, seasoned clinicians are attentive to a wide variety of dimensions of a clinical encounter and reasoning cannot be successful if some of these dimensions are neglected. A narrow view of the multidimensional nature of clinical reasoning may explain the paucity of methods available to medical educators for fostering the acquisition of clinical reasoning skills, detecting learners with deficiencies in clinical reasoning, and offering appropriate remediation to those who have been identified as learners in trouble.[7–10] Although some clinical reasoning difficulties may be linked to clearly delineated steps in the reasoning process (e.g. 'data gathering' or 'hypothesis generation'), others may be ascribed to less commonly identified factors, such as ability to appreciate the clinical context, ability to deal with uncertainty, or ability to communicate effectively. The relationship between these factors and clinical reasoning is rarely discussed in the literature. Our model may be a useful tool for bringing these crucial yet often overlooked dimensions of clinical reasoning to light for the benefit of discussion and instruction among teachers and learners.

Written assessments of clinical reasoning typically provide a brief clinical context and then ask questions such as 'What is the correct or most probable diagnosis?' or 'What is the most relevant investigation or treatment option?' Such formats assess the outcome of clinical reasoning, rather than its processes. As long as the right answer is provided by the learner, reasoning is considered acceptable and no regard is paid to how the answer is obtained. In such instances, educators who assess clinical reasoning do not actually have access to learners' reasoning processes and are therefore unable to identify whether important elements are lacking or are being misused. Educators are therefore generally good at detecting 'those who do not have it', but are rarely able to point out precisely where in a learner's reasoning processes about a particular case the problem lies, and thus have difficulty designing appropriate remediation activities.[10] The MOT model can be used as a guide to test specific parts of learners' clinical reasoning processes, and therefore to help pinpoint flaws in reasoning as learners reason through clinical encounters. Remediation activities can then be designed to target these specific areas of difficulty.

Study limitations

This study has several limitations. The 12 CVs were all doctors; health professionals from other health-related disciplines were therefore under-represented in this particular cohort. Furthermore, the six clinicians who participated in the iterative knowledge extraction and modelling sessions were all strongly implicated in the teaching of clinical reasoning, were all informed of the literature on clinical reasoning, and had more than basic knowledge of cognitive sciences. They were inevitably influenced by these concepts from the literature and perceived them as critical both for unravelling their own clinical reasoning processes and for facilitating clinical education. However, that the CPs held these characteristics can be viewed as a strength as well as a limitation of the study because the research method – participatory action research – borrows techniques from qualitative methodology, in which the co-construction process is carried out collaboratively by a group of people who are interested in changing practice in their setting.

It is interesting to consider whether reasoning processes and their representations would have been different had the study involved other CPs and another cognitician. It is likely that the model would differ in detail, as symbols (ovals, rectangles, arrows) can be arrayed in slightly different manners, with no ultimate consequence for conceptualisation. However, the nature of the processes and the nature of links are another matter. A first concern refers to whether all key processes have been unveiled. As knowledge extraction was undertaken in multiple sessions in an iterative way, we think that participants' conscious reasoning processes continued to reveal themselves until saturation was reached; only findings from research using similar or other techniques will confirm or refute this. A second concern refers to how realistically these cognitive operations are depicted. In this respect the MOT software and technique offer significant advances over previous tools used for the purpose of deriving cognitive maps.

The rules inherent in the modelling technique in MOT Plus often led to the detection of logical errors during the construction of models. Links that did not accurately express the experts' knowledge indicated that the model probably contained a logical error. By probing participants further it was possible to correct the mistake and enhance the precision of the map. Additionally, the graphical layout of the model often revealed possible faulty interpretations. For example, the grammar in MOT Plus very rarely allows links to cross. When this situation arises, analysis almost always shows that knowledge is incorrectly interpreted or that the model is incomplete. Within the sessions, resolving these issues often revealed tacit knowledge that had not surfaced before.

CONCLUSIONS

The MOT model constitutes an explicit graphical representation of the multifaceted processes of clinical reasoning. Its validity across disciplines and situations needs to be confirmed, but it has the potential to inform the acquisition, teaching and assessment of clinical reasoning skills, to help clinical educators identify flawed reasoning processes in their students and residents and design appropriate remediation activities, and to orient future research studies that aim to unravel more of the complexities of clinical reasoning.

Contributors: BC co-led the conception and design of the study and is a principal co-author of the manuscript. SL participated in the validation session and is a principal co-author of the paper. BM conceived and organised the validation session. FC co-led the conception and design of the study. BC, FC, M-CA, AC, NC and CB served as clinician-participants and were responsible for developing the ideas and analysing the findings of the study. LH described the technical aspects of MOT methodology and wrote a preliminary version of the paper. All authors contributed to the critical revision of the paper for intellectual content and approved the final manuscript for submission.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article.

Figure S1. Process: 'Identify early cues'.

Figure S2. Process: 'Regulate cognitive processes'.

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