The student is key: a realist review of educational interventions to develop analytical and non-analytical clinical reasoning ability

Anna Richmond[1,2], Nicola Cooper[3], Simon Gay[4], William Atiomo[2] and Rakesh Patel[1]

Affiliations –

1. Education Centre, School of Medicine, University of Nottingham, UK
2. Department of Obstetrics and Gynaecology, School of Medicine, University of Nottingham, UK
3. Department of Acute Medicine, University Hospitals of Derby and Burton NHS Foundation Trust, UK
4. School of Medicine, University of Leicester, Leicester, UK

WORD COUNT (excl abstract, tables, figs and references): 3,962

Abstract

Background Clinical reasoning refers to the cognitive processes used by individuals as they formulate a diagnosis or treatment plan. Clinical reasoning is dependent on formal and experiential knowledge. Developing the ability to acquire and recall knowledge effectively for both analytical and non-analytical cognitive processing has patient safety implications. This realist review examines the way educational interventions develop analytical and non-analytical reasoning ability in undergraduate education. A realist review is theory-driven seeking not only to identify if an intervention works, but also understand the reasons why, for whom, and in what circumstances.

Aim To develop understanding about the way educational interventions develop effective analytical and non-analytical clinical reasoning ability, when they do, for whom and in what circumstances.

Methods Literature from a scoping search, combined with expert opinion and researcher experience was synthesised to generate an initial programme theory (IPT). Four databases were searched and articles relevant to the developing theory were selected as appropriate. Factors affecting educational outcomes at the individual student, teacher and wider organisational levels were investigated in order to further refine the IPT.

Results 28 papers contributed to the overall programme theory. The review predominantly identified evidence of mechanisms for interventions at the individual student level. Key student level factors influencing the effectiveness of interventions included an individual's pre-existing level of knowledge and self-confidence and self-efficacy. These contexts influenced a variety of educational interventions, impacting both positively and negatively on educational outcomes.

Discussion Development of analytical and non-analytical clinical reasoning ability requires activities that enhance knowledge acquisition and recall alongside the accumulation of clinical experience and opportunities to practise reasoning in real or simulated clinical environments. However, factors such as pre-existing knowledge and self-confidence influence their effectiveness, especially among individuals with 'low knowledge'. Promoting non-analytical

reasoning once novices acquire more clinical knowledge is important for the development of clinical reasoning in undergraduate education.

Introduction

Medical students need to develop safe and effective clinical reasoning ability during their training prior to entering the workplace as practising doctors (1). Clinical reasoning can be defined as *a skill, process, or outcome* in which clinicians observe, collect, and interpret data to diagnose and treat patients (2). There is a growing body of evidence in the literature confirming the importance of knowledge and clinical experience for improving clinical reasoning ability (3). However, merely acquiring factual knowledge and clinical experience is insufficient for developing clinical reasoning expertise. The ways in which one mobilises and applies that knowledge when faced with clinical problems or presentations is also important (4).

Researchers describe two complementary approaches for processing information during clinical reasoning. Non-analytical reasoning involves unconscious information processing without the effortful use of working memory (5) and is triggered when individuals recognise or have a sense of familiarity with a clinical presentation. Analytical reasoning is triggered when individuals have little or no sense of familiarity with a clinical presentation and involves effortful use of working memory alongside a careful deliberation over various diagnostic possibilities. Over time and particularly among experts, non-analytical approaches are typically used for the majority of everyday problem-solving and decision-making. Conversely, experts are also effective at recognising when 'things do not fit' and capable of consciously switching to more analytical approaches when necessary (6).

A number of educational interventions are described for developing non-analytical and analytical clinical reasoning skills. The majority teach the analytical processes of reasoning and increasing awareness about cognitive biases (7). These interventions assume by being more 'mindful' about thinking and 'bringing reasoning' into consciousness, individuals may mitigate the impact of particular error-prone biases. Evidence supporting these interventions are inconclusive (8). However, interventions that develop knowledge alongside promoting analytical reasoning approaches have demonstrated benefit on diagnostic performance (9, 10). That said, these interventions have not led to benefit for all learners, or across different reasoning tasks.

The observation that reasoning ability does not easily transfer across different contexts is not new (11) nor is the observation that some educational interventions are more effective in some settings than others. This presents a significant challenge for medical educators given clinical presentations are getting more complex and diagnostic uncertainty for learners is another growing problem. Given the imperative for developing effective reasoning skills among learners by the point of graduation, it is important to better understand the reasons why interventions work, for whom they work for, and in what circumstances. Healthcare professions education is context specific, therefore factors such as the type of learner, the type of teaching and instructional design, as well as the organisational structure in which the education is delivered are all relevant when making sense of the effectiveness of interventions. Therefore, any search for effective educational interventions requires scruinty not only of their efficacy, but also the contexts and circumstances in which they are effective.

Realism is a philosophical perspective that places emphasis on both context and causality. Realist research attempts to illuminate why, how, for whom and in what circumstances interventions work or not (12). A linear causal relationship between the intervention and outcome is not assumed from this perspective, but instead there is acknowledgement of complexity and generative causation dependant on various contexts in which the intervention operates (13). This study aims to develop theory-driven understanding about the way educational interventions develop effective analytical and non-analytical clinical reasoning, when they do, for whom and under what circumstances. The research questions that emerged from this aim were: 'What educational interventions are effective for developing analytical and non-analytical clinical reasoning ability among medical students? When and why are they effective, for whom and in what circumstances?'

Methodology

Realist research data are analysed and interpreted to form context, mechanism, outcome configurations (CMOCs) and collectively form a programme theory (12). In this analytical framework, contexts are separate to the intervention being investigated but affect how the intervention is received by participants. Context is assumed to be neutral in systematic reviews, whereas context is viewed differently from a realist perspective and integral to understanding reasons for success or failure of an intervention (13). Mechanisms are conceptualised as resources and responses: interventions offer resources into a context, effecting a change in participants' responses, which in turn leads to various outcomes (14). Mechanisms, particularly the cognitive or emotional responses of the learners, are not always explicit and may be difficult to ‘see’. Therefore, mechanisms can be theorised from existing theories of learning or inferred from data in the review process (15). Outcomes are the measured effects of interventions. All possible outcomes may also not be explicit, therefore, outcomes can be also theorised in the same way. In this review, diagnostic accuracy or effective learning about clinical reasoning as a process (e.g. knowledge of case exemplars or illness script formation), were used as the outcome measures. Both the short term measures of ability (diagnostic accuracy or error) and longer term measures of ability (development of process components over time) were included (16).

Method

The review was registered on PROSPERO: International Prospective Register of Systematic Reviews (CRD42017072029). The RAMESES publication standards for realist synthesis (12) were referred to throughout the review. Initial background literature searches relating to educational interventions around clinical reasoning and dual-process theory was undertaken by AR. All members of the research team were clinical teachers with expertise in the development and education of clinical reasoning at under-, post-graduate and Masters level (7) (17) (18). AR developed consensus among the research team about educational interventions that promote non-analytical or analytical processes during clinical reasoning tasks. The outputs from the background literature search and consensus building led to the development of initial drafts of CMOCs. Following feedback from the research team, an initial programme theory (IPT) was constructed from these drafts. The scope of review was restricted to undergraduate medical or healthcare professions education.

Other relevant theories were also intergrated into the IPT. Cognitive flexibility theory (CFT) (19) posits that all learning is context dependant and for successful transfer of learning in future encounters, learning should occur within multiple scenarios and contexts. Situativity theory (20) also asserts the importance of context within learning, specifically that learning is “situated in experience”(20), with particular attention given to different contextual levels. These insights directed searching for contexts at the level of the student, the teacher and learning encounter/activity. Such an approach to theorising different contextual levels has been reported in a previous realist review (21).

Search strategy and appraisal

[Figure 1 here]

Figure 1 shows the PRISMA diagram for the review. Structured searches of Medline, PsycINFO, ERIC (Education Resource Information Centre) and CINAHL were performed in May 2017, incorporating key themes developed from the IPT (supplementary file 1). Searching began from the year 2000 following the publication in 1999 of the seminal paper 'To err is human' (22) which brought diagnostic error and clinical reasoning into the mainstream consciousness of the healthcare community and global public. A supplementary search to incorporate additional terms, such as pattern recognition, deliberate practice (23), illness scripts (24) knowledge acquisition and recall (25) was also performed since initial searching highlighted these concepts as relevant to medical expertise development and non-analytical reasoning. The conceptualisation of the 'knowledge' relevant to this review was multidimensional as defined in Table 1.

[Table 1 here]

The title-abstract screen assessed for relevance (see supplementary file 1) and studies retrieved if they were deemed to contribute to theory building (12). Methodological rigour, were the methods credible and trustworthy (12), was further assessed at full text review. An educational intervention was defined as 'a teaching process or method for developing knowledge and skills or delivering information to an individual or group' for the full stage review. Some studies describing a technique that could be integrated into an intervention (for example experimental studies that promoted a specific reasoning style by giving instructions at the time of the test (26-31)) were included in the analysis. Reference lists of included full texts were also searched for relevant papers that could contribute to theory building (n=2).

Data extraction, analysis and synthesis

CMOCs were devised for all included full texts. Initial CMOC coding was undertaken by AR and all 28 articles were checked for consistency by another reviewer (RP, SG or NC). Data extraction forms were kept for all reviewed full texts (see supplementary file 1). Comparisons were made between studies and recurrent patterns of CMOCs were identified. Some studies particularly highlighted contexts whereas others shed more light on mechanisms. Studies identified earlier were re-analysed in light of theories arising from papers included later in the review (12). The aim of this review focuses on theory building rather than testing as often interventions or outcomes of interest were under-reported or too distant (21, 32). NVivo© (NVivo v.12.1.0, QSR International Pty Ltd) was used to store full texts and code contexts. Excel© (Microsoft Excel v.16.6.4, Microsoft Corporation) was used to further elaborate which contexts affected the mechanisms and outcomes. Key contexts and mechanisms for determining effectiveness were eventually produced as outputs from the synthesis through this iterative process.

Results

Study characteristics

In total, 149 full texts were retrieved. Of these, 25 articles met the inclusion criteria, and two more were added from reference list searching (33). One was added from a subsequent search of learning strategies to promote knowledge retention. Details of the included papers are available in supplementary file 2. Of the included papers, three were from the UK, eleven from Canada, three from the USA, two from Germany, three from the Netherlands and six from other countries. Twenty-three studies were described in medical education, one was from veterinary education and four involved psychology students. The total number of participants across the studies was 1495.

Outcomes in the selected studies were heterogenous with most defining diagnostic accuracy as the primary clinical reasoning end-point (n=13). Some studies reported more than one measured outcome. Seven studies reported student satisfaction and seven reported a change in knowledge. Five studies detailed interventions that were theorised to promote illness script and non-analytical reasoning development. No outcomes were reported in one study but the findings contributed to understanding about potential mechanisms for possible outcomes (34).

Theory development and refinement

The selected studies identified key contexts for clinical reasoning interventions at the individual level, with contexts at the teacher or the wider organisation level rarely discussed. Therefore, the results presented below predominantly focus on individual student level contexts. Five key contexts were identified: 1) students with 'low knowledge', low clinical domain specific knowledge, or an inability to use knowledge in a reasoning situation; 2) students with high clinical domain specific knowledge; 3) positive student coping strategies or appropriate level of self-confidence/self-efficacy; 4) negative student coping strategies or lacking self-confidence/self-efficacy and 5) students with different levels of knowledge within a group.

The results are shown in Figure 2 and are presented for each of these five contexts in turn with a CMOC statement (in italics) followed by an explanation of the supporting evidence for the CMOC.

[Figure 2 here]

Context 1: **Students with 'low knowledge', low clinical domain specific knowledge, or an inability to use knowledge in a reasoning situation**

When students have low knowledge, low domain specific knowledge or an inability to apply their knowledge in a reasoning situation (Context; C), there are multiple ways (Mechanism – resource; Mresource) in which educational interventions may develop their diagnostic accuracy or reasoning ability (Outcome; O). The context of low knowledge (C) combines with different resources to produce varying emotional and cognitive responses *in the students (Mechanisms –* response*; M*response*) which either promote positive or negative educational outcomes (O).*

Twenty two studies contributed to developing this theory (9, 26-31, 34-48) and this context exerted most influence on the interventions. The many ways this context affected mechanisms and outcomes is shown in Figure 3. For example, when students with insufficient knowledge passively observe experts without receiving an explanation of the experts reasoning. They may experience panic or resentment at not immediately knowing how the expert has made a decision and are not able to fully develop their own understanding about the clinical problem. Conversely, students who receive a full and explicit explanation of an experts' reasoning tend to have positive learning experiences since they have clear insight into, and can make sense of, an experts' diagnostic decision-making pathway.

This context is particularly relevant to much of undergraduate education since many students are essentially novices in most clinical situations. Furthermore, many students may have 'low knowledge' relative to the clinical reasoning challenge even though they may have 'adequate knowledge' in general for their stage of training. Likewise, students may be perceived as having 'low knowledge' when unable to apply their knowledge appropriately.

[Figure 3 here]

Context 2: High clinical domain specific knowledge student

*When an expert's reasoning processes or thoughts are explicitly revealed and discussed (Mresource) with students with sufficient domain specific knowledge (C), this promotes understanding (M*response*) leading to insight (M*response*) into the reasoning process when diagnosing and managing patients (O) and a positive learning experience (O).*

*When students with high clinical domain specific knowledge (C) are instructed to use analytical reasoning alone or this is promoted by ensuring they think through all aspects of the case (Mresource), they may feel frustrated (M*response*) as they can rely on non-analytical reasoning (M*response*) and still attain high diagnostic accuracy (O).*

Seven studies contributed to this theory (8, 9, 30, 37, 43, 49, 50) and including insights from the expertise development literature (23). Sufficient knowledge and experience enable relatively accurate non-analytical reasoning in this context, with students naturally developing more rapid, intuitive reasoning as their knowledge and experience increases. Students with higher subject-specific knowledge may benefit more from discussions with teachers and experts explaining their reasoning as they develop a good understanding of the clinical domain. Likewise, students with sufficient clinical domain specific knowledge derive little benefit from being stretched for explanations, or when directive teaching approaches commonly reserved for 'low knowledge' students, are used on them.

***Context 3:* Positive student coping strategies or appropriate level of self-confidence/self-efficacy**

*When students with the ability to cope with the challenge of performing clinical reasoning (C) or students with an appropriate level of self-confidence/self-efficacy calibrated to previous clinical reasoning performance (C) are exposed to teaching resources that allow them to make mistakes (Mresource) or those based in real-life scenarios (Mresource), including simulation and simulated patients, they feel grateful for the learning experience (M*response*). The experience enables them to build understanding (M*response*) which has a positive impact on learning (O) and this is important to developing more complete illness scripts and performing more accurate non-analytical reasoning (O).*

*When students with positive coping strategies (C) are exposed to real cases (Mresource) they feel pressure that their decision making could have a real impact (M*response*) which results in a positive learning experience (O).*

Five studies contributed to this theory (35, 36, 45, 49, 50). Feelings of stress in simulated or real environments can be intrinsic or extrinsic to the task (51). When those emotions are perceived by the individual as being necessary for performing the task, they may enhance knowledge acquisition. Conversely, when emotions are perceived as peripheral to the task or distractors, performance on task may be impaired. The way individuals perceive emotional triggers as a threats or opportunities vary according to the extent individuals have developed sufficient coping strategies when performing on task. Experience, practice and making mistakes (52) are vital to developing clinical reasoning ability and students with positive coping strategies or appropriately high levels of self-confidence will gain most from educational interventions that provide this resource.

***Context 4:* Negative student coping strategies or lacking self-confidence/self-efficacy**

*Students with poor coping strategies or low self-confidence/self-efficacy beliefs calibrated to previous clinical reasoning performance (C,) exposed to simulated or real patient encounters (Mresources), may experience fear (M*response*), stress (M*response*) or pressure to perform*

*(M*response*). As a consequence, cognitive load is increased (M*response*) resulting in poor illness script development, faulty future non-analytical reasoning and negative learning outcomes (O).*

Four studies contributed to this theory (35, 45, 49, 50) including insights from cognitive load theory (53) and human stress responses (51, 54). Negative outcomes result from students' inability to cope with the stress of simulated or real environments and from making mistakes. Whilst simulation allows students to learn from cases they might otherwise not encounter in the workplace or make mistakes without the fear of punishment (52), not all students will make learning gains in these situations.

Context 5: Students with different levels of knowledge within a group

*When teaching students with different levels of pre-existing knowledge in a group (C), using strategies that promote knowledge retention (Mresource) will build upon what they already know (M*response*) and develop understanding (M*response*) regardless of their pre-existing knowledge level, which leads to increased learning (O) and further engagement (O).*

*Providing accurate and timely feedback (Mresource) is an important component of developing reasoning skills in students with all levels of knowledge (C), to develop understanding (M*response*) of their successes and failures and generate plans for improvement. This is more likely to promote development of complete illness scripts (M*response*) and successful non-analytical reasoning in the future (O). When feedback is absent, incomplete or contains errors (Mresource) this can lead to confusion (M*response*) and have a negative impact on learning (O).*

Nine studies contributed to this theory (29, 39, 42, 45, 46, 50, 55-57). The educational challenge for teachers is to deliver teaching experiences to students with varying levels of pre-existing knowledge. The most effective way was to provide timely and accurate feedback on performance as well as use strategies that promoted long term retention of knowledge. One effective strategy was to integrate test-enhanced learning into the teaching of clinical reasoning (58). Conversely, leaving students without feedback on their reasoning ability or providing erroneous feedback led to confusion, reduced understanding and impaired clinical reasoning development.

Discussion

This research demonstrates that educational interventions seeking to develop effective analytical and non-analytical clinical reasoning ability among undergraduate students 'do not work' independently, but 'work inter-dependently' with the individual, their pre-existing clinical domain specific knowledge and their ability to cope with the clinical reasoning task. The research identified five contexts, and is the first study to report, the same educational intervention 'may work' across many contexts, but the effect is not the same across them all, especially among students with low knowledge states. Furthermore, this research provides more evidence to the growing consensus that a 'one-size fits all' approach to delivering education is becoming less effective, especially for clinical reasoning teaching, given the negative outcomes identified when students are given tasks beyond their competence or reach, even with a teacher present with them as they perform.

The 'Matthew effect' is well-described in the educational literature and suggests that better pre-existing knowledge of an individual correlates with higher educational achievement (59). This research provides further evidence for this observation and suggests identifying the level of knowledge a student possesses for a given task or across a particular knowledge domain is necessary for predicting which educational interventions will be effective for them. Often knowledge levels are assumed among students based on their year of study, having progressed through high-stakes assessments, or their accumulated total experience over a programme. Time spent on a course is a poor marker of competence (60) and this realist review suggests a given intervention may not have the same impact on all students, especially those with low knowledge states who need support the most. Furthermore, improving knowledge for clinical reasoning has been highlighted as the most promising area to improve diagnostic accuracy and reduce error (4, 61, 62). This review supports that call and the findings suggest improving knowledge structures and long term knowledge retention for later recall is essential for the development of both confidence and competence in clinical reasoning.

Although not the main focus of the review, students with low knowledge states featured heavily as targets for educational interventions to develop analytical and non-analytical clinical reasoning ability. Effective teaching and learning strategies are particularly important among this group of learners since they provide the greatest challenge for clinical teachers. Retrieval practice, interleaving and spaced practice are examples of learning strategies which induce 'desirable difficulties' among learners and demonstrate the promising outcomes for constructing knowledge and effective transfer into memory (63). These strategies promote long term retention of knowledge by encouraging learners to revisit material over time, practice retrieving stored information in a variety of ways (such as quizzes or questioning) and mix different subjects together when studying rather than learn topics in silos (64, 65). Educators could use these strategies to increase knowledge retention prior to, or alongside experiences in simulated or real environments, so learners have sufficient knowledge not just for illness script formation and development initially, but also refinement after receving feedback from teachers following performance on task.

Whilst the assertion that increasing knowledge is necessary improving 'thinking' for clinical reasoning is still being debated (66), the recommendation for more exposure to real patients in any environment for improving performance causes few objections. This research identified that exposure to real patients in practice or simulated environments was necessary for making 'safe mistakes' (52) and providing a 'safe place' for students to also develop coping strategies prior to becoming doctors. Furthermore, this experience was seen as 'part and parcel' of becoming a doctor, but also one of the few educational opportunities where students could feel the emotions evoked when clinical reasoning for real. Whilst the review set out to identify effective interventions for developing cognitive information-processing pathways associated with clinical reasoning, the findings demonstrate the self-management of emotions evoked as a result both non-analytical and analytical thinking are also important, in the development of clinical reasoning ability.

Finally, educational interventions for clinical reasoning have tended to privilege approaches for developing analytical information processing (67). However, the findings from this review suggest educational interventions for undergraduate students could do more to encourage students towards non-analytical reasoning even when individuals have developed a sufficiently high level of knowledge within the clinical domain. The challenge for educators now is to identify baseline clinical reasoning knowledge using new educational technologies, monitor diagnostic decision-making development over time (68) and provide feedback about which approaches need further improvement at the level of the individual. Furthermore, the challenge is not just about 'monitoring for the sake of monitoring' but also identifying key self-regulatory behaviours known to affect confidence or self-efficacy when students with low or high knowledge states undertake clinical reasoning tasks (69). Providing all this information for the educator in a way that is useful to them and useable for the learner is the most important first step in the process. Thereafter both learner and teacher will hopefully be able to identify the most appropriate educational support for improving their clinical reasoning ability, especially given there are at least five different contexts in which the same intervention may have a completely different effect.

Strengths and limitations

Although there are various reviews of clinical reasoning interventions highlighting what may 'work' in terms of improving diagnostic performance (70, 71), this is the first realist review to identify why interventions may work, for whom and the contexts in which they work. The outputs from this synthesis add to this knowledge base by providing useful, practical information for teachers responsible for developing both analytical and non-analytical thinking ability of undergraduate students, especially those with low knowledge states. Realist methodology encourages inferences to be made in an iterative way by triangulating insights from other sources to increase the accuracy of results rather than disregard the evidence altogether. Likewise, not all outcomes or impacts from educational interventions may be explicitly reported by researchers even though they may be apparent when findings are read through different methodological or displinary lens. Better reporting standards for interventions should increase the quality of descriptions and synthesis using realist methods in the future.

Conclusions

Educational interventions for developing analytical and non-analytical reasoning among undergraduate students in medical or healthcare professions education predominantly work by increase knowledge acquisition, mobilisation and recall alongside encouraging practice in real or simulated environments. Students with low knowledge states affect moreso whether educational interventions are successful or not, therefore identifying what individuals know about a particular clinical problem or across a knowledge domain is important. Students with developing expertise should be encouraged to use non-analytical reasoning just like experts do on task, switching back to analytical reasoning when faced with complexity or uncertainty and needing to explain their thinking.

Contributions: AR, WA and RP conceived the study and contributed towards initial theory development. AR developed the protocol, performed the searches, performed initial data extraction, synthesised the results, created visual representations of the data and wrote the initial draft manuscript. RP, SG and NC reviewed a sample of full texts and provided feedback on the developing theory and manuscript. AR, RP and NC contributed to the manuscript. WA is the principal supervisor of AR's PhD, of which this study forms a part. All authors agreed the final manuscript prior to submission.

References

1. Outcomes For Graduates (Tomorrow's doctors). The General Medical Council; 2015.
2. Daniel M, Rencic J, Durning SJ, Holmboe E, Santen SA, Lang V, et al. Clinical Reasoning Assessment Methods: A Scoping Review and Practical Guidance. Acad Med. 2019;94(6):902-12.
3. Monteiro S, Norman G, Sherbino J. The 3 faces of clinical reasoning: Epistemological explorations of disparate error reduction strategies. Journal of Evaluation in Clinical Practice. 2018;24(3):666-73.
4. Norman GR, Eva KW. Diagnostic error and clinical reasoning. Med Educ. 2010;44(1):94-100.
5. Evans JSBT, Stanovich KE. Dual-process Theories of Higher Cognition: Advancing the Debate. Perspectives on Psychological Science. 2013;8(3):223-41.
6. Norman G, Trott A, Brooks L, Smith E. Cognitive differences in clinical reasoning related to postgraduate training. Teaching and learning in medicine. 1994;6:114-20.
7. Gay S, Bartlett M, McKinley R. Teaching clinical reasoning to medical students. Clin Teach. 2013;10(5):308-12.
8. Sherbino J, Kulasegaram K, Howey E, Norman G. Ineffectiveness of cognitive forcing strategies to reduce biases in diagnostic reasoning: a controlled trial. Cjem. 2014;16(1):34-40.
9. Chamberland M, Mamede S, St-Onge C, Rivard MA, Setrakian J, Levesque A, et al. Students' self-explanations while solving unfamiliar cases: the role of biomedical knowledge. Medical Education. 2013;47(11):1109-16.
10. Prakash S, Sladek R, Schuwirth L. Interventions to improve diagnostic decision making: a systematic review and meta-analysis on reflective strategies. Medical teacher. 2018;41(5):517-24.
11. Eva KW. What every teacher needs to know about clinical reasoning. Med Educ. 2004;39:98-106.
12. Wong G, Greenhalgh T, Westhorp G, Buckingham J, Pawson R. RAMESES publication standards: realist synthesis. BMC Medicine. 2013;11(21).
13. Pawson R. Evidence-based Policy. A realist perspective. London: SAGE; 2006.
14. Dalkin SM, Greenhalgh J, Jones D, Cunningham B, Lhussier M. What's in a mechanism? Development of a key concept in realist evaluation. Implement Sci. 2015;10:49.
15. Wong G, Greenhalgh T, Westhorp G, Pawson R. Realist methods in medical education research: what are they and what can they contribute? Med Educ. 2012;46(1):89-96.
16. Hautz WE. When i say…diagnostic error. Medical Education. 2018;52(9):896-7.
17. Cooper N, Frain J. ABC of Clinical Reasoning. 1st ed. Chichester: Wiley Blackwell/ BMJ Publishing Group; 2016.
18. Patel RS, Sandars J, Carr S. Clinical diagnostic decision-making in real life contexts: A trans-theoretical approach for teaching: AMEE Guide No. 95. Medical teacher. 2015;37(3):211-27.

19. Spiro RJ, Coulson RL, Feltovich PJ, Anderson D, editors. Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. 10th Annual Conference of the Cognitive Science Society; 1988; Hillsdale, NJ.

20. Durning SJ, Artino AR. Situativity Theory: a perspective on how participants and the environment can interact: AMEE guide No. 52. Medical teacher. 2011;33(3):188-99.

21. Kehoe A, McLachlan J, Metcalf J, Forrest S, Carter M, Illing J. Supporting international medical graduates' transition to their host-country: realist synthesis. Med Educ. 2016;50(10):1015-32.

22. Kohn LT, Corrigan JM, Donaldson MS. To Err is Human: building a safer health system. Washington DC: Institute of Medicine; 1999.

23. Ericsson A. Deliberate Practice and the Acquisition and Maintenance of Expert Performance in Medicine and Related Domains. Academic Medicine. 2004;70(10):S70-S81.

24. Custers EJFM. Thirty years of illness scripts: Theoretical origins and practical applications. Medical teacher. 2015;37(5):457-62.

25. Weinstein Y, Madan CR, Sumeracki MA. Teaching the science of learning. Cogn Res Princ Implic. 2018;3(1):2.

26. Kulatunga-Moruzi C, Brooks LR, Norman GR. Coordination of analytic and similarity-based processing strategies and expertise in dermatological diagnosis. Teaching and Learning in Medicine. 2001;13(2):110-6.

27. Ark TK, Brooks LR, Eva KW. Giving Learners the Best of Both Worlds: Do Clinical Teachers Need to Guard Against Teaching Pattern Recognition to Novices? Academic Medicine. 2006;81(4):405-9.

28. Eva KW, Hatala RM, Leblanc VR, Brooks LR. Teaching from the clinical reasoning literature: combined reasoning strategies help novice diagnosticians overcome misleading information. Medical Education. 2007;41(12):1152-8.

29. Ark TK, Brooks LR, Eva KW. The benefits of flexibility: the pedagogical value of instructions to adopt multifaceted diagnostic reasoning strategies. Medical Education. 2007;41(3):281-7.

30. Myung SJ, Kang SH, Phyo SR, Shin JS, Park WB. Effect of enhanced analytic reasoning on diagnostic accuracy: A randomized controlled study. Medical teacher. 2013;35(3):248-50.

31. Evered A, Walker D, Watt AA, Perham N. To what extent does nonanalytic reasoning contribute to visual learning in cytopathology? Cancer Cytopathol. 2013;121(6):329-38.

32. Davies F, Wood F, Bullock A, Wallace C, Edwards A. Shifting mindsets: a realist synthesis of evidence from self-management support training. Medical Education 2018;52:274-87.

33. Haig A, Dozier M. BEME guide no. 3: systematic searching for evidence in medical education--part 2: constructing searches. Medical teacher. 2003;25(5):463-84.

34. Linn A, Khaw C, Kildea H, Tonkin A. Clinical reasoning. A guide to improve teaching and practice. Australian Family Physician. 2012;41(1/2).

35. Bender HS, Danielson JA. A novel educational tool for teaching diagnostic reasoning and laboratory data interpretation to veterinary (and medical) students. Clinics in Laboratory Medicine. 2011;31(1):201-15.

36. Graafland M, Vollebergh MF, Lagarde SM, van Haperen M, Bemelman WA, Schijven MP. A serious game can be a valid method to train clinical decision-making in surgery. World Journal of Surgery. 2014;38(12):3056-62.

37. Nendaz MR, Gut AM, Louis-Simonet M, Perrier A, Vu NV. Bringing explicit insight into cognitive psychology features during clinical reasoning seminars: a prospective, controlled study. Education for Health: Change in Learning & Practice (Medknow Publications & Media Pvt Ltd). 2011;24(1):13p-p.

38. Borleffs JC, Custers EJ, van Gijn J, ten Cate OT. "Clinical Reasoning Theater": A new approach to clinical reasoning education. Academic Medicine. 2003;78(3):322-5.

39. Klamen DL, Williams RG. The efficacy of a targeted remediation process for students who fail standardized patient examinations. Teaching and Learning in Medicine. 2011;23(1):3-11.

40. Jacobson K, Fisher DL, Hoffman K, Tsoulas KD. Integrated cases section: A course designed to promote clinical reasoning in year 2 medical students. Teaching and Learning in Medicine. 2010;22(4):312-6.

41. Mamede S, van Gog T, Moura AS, de Faria RMD, Peixoto JM, Rikers RMJP, et al. Reflection as a strategy to foster medical students' acquisition of diagnostic competence. Medical Education. 2012;46(5):464-72.

42. Blissett S, Cavalcanti RB, Sibbald M. Should we teach using schemas? Evidence from a randomised trial. Medical Education. 2012;46(8):815-22.

43. Chamberland M, St-Onge C, Setrakian J, Lanthier L, Bergeron L, Bourget A, et al. The influence of medical students' self-explanations on diagnostic performance. Medical Education. 2011;45(7):688-95.

44. Coderre S, Wright B, McLaughlin K. To Think Is Good: Querying an Initial Hypothesis Reduces Diagnostic Error in Medical Students. Academic Medicine. 2010;85(7).

45. Pinnock R, Spence F, Chung A, Booth R. evPaeds: undergraduate clinical reasoning. Clin Teach. 2012;9(3):152-7.

46. Adams E, Rodgers C, Harrington R, Young M, Sieber V. How we created virtual patient cases for primary care-based learning. Medical teacher. 2011;33(4):273-8.

47. Chamberland M, Mamede S, St-Onge C, Setrakian J, Bergeron L, Schmidt H. Self-explanation in learning clinical reasoning: the added value of examples and prompts. Medical Education. 2015;49(2):193-202.

48. Chamberland M, Mamede S, St-Onge C, Setrakian J, Schmidt HG. Does medical students' diagnostic performance improve by observing examples of self-explanation provided by peers or experts? Advances in Health Sciences Education. 2015;20(4):981-93.

49. McGregor CA, Paton C, Thomson C, Chandratilake M, Scott H. Preparing medical students for clinical decision making: a pilot study exploring how students make decisions and the perceived impact of a clinical decision making teaching intervention. Medical teacher. 2012;34(7):e508-17.

50. Bloice MD, Simonic KM, Holzinger A. Casebook: a virtual patient iPad application for teaching decision-making through the use of electronic health records. BMC Medical Informatics & Decision Making. 2014;14:66.
51. Pottier P, Hardouin J-B, Dejoie T, Castillo J-M, Le Loupp A-G, Planchon B, et al. Effect of extrinsic and intrinsic stressors on clinical skills performance in third-year medical students. Journal of General Internal Medicine. 2015;30(9):1259-69.
52. Eva KW. Diagnostic error in medical education: where wrongs can make rights. Advances in Health Sciences Education. 2009;14:71-81.
53. Young JQ, Van Merrienboer J, Durning S, Ten Cate O. Cognitive Load Theory: implications for medical education: AMEE Guide No. 86. Medical teacher. 2014;36(5):371-84.
54. LeBlanc VR. The Effects of Acute Stress on Performance: Implications for Health Professions Education. Academic Medicine. 2009;84(10).
55. Kopp V, Stark R, Fischer MR. Fostering diagnostic knowledge through computer-supported, case-based worked examples: effects of erroneous examples and feedback. Medical Education. 2008;42(8):823-9.
56. Boshuizen HPA, van de Wiel MWJ, Schmidt HG. What and How Advanced Medical Students Learn from Reasoning through Multiple Cases. Instructional Science: An International Journal of the Learning Sciences. 2012;40(5):755-68.
57. Raupach T, Andresen JC, Meyer K, Strobel L, Koziolek M, Jung W, et al. Test-enhanced learning of clinical reasoning: a crossover randomised trial. Medical Education. 2016;50(7):711-20.
58. Baghdady M, Carnahan H, Lam EW, Woods NN. Test-enhanced learning and its effect on comprehension and diagnostic accuracy. Medical Education. 2014;48(2):181-8.
59. Walberg HJ, Tsai S-L. 'Matthew' Effects in Education. American Educational Research Journal. 1983;20(3).
60. Frank J, Snell L, Ten Cate O, Holmboe E, Carraccio C, Swing S, et al. Competency-based medical education: theory to practice. Medical teacher. 2010;32(8):638-45.
61. Monteiro. S, Sherbino. J, Sibbald. M, Norman. G. Critical thinking, biases and dual processing: The enduring myth of generalisable skills. Medical Education. 2019;Online ahead of print.
62. Norman GR, Monteiro SD, Sherbino J, Ilgen JS, Schmidt HG, Mamede S. The Causes of Errors in Clinical Reasoning: Cognitive Biases, Knowledge Deficits, and Dual Process Thinking. Acad Med. 2017;92(1):23-30.
63. Brown PC, Roediger HL, McDaniel MA. Make it stick: The science of successful learning. USA: Harvard University Press; 2014.
64. Saville BK, Lambert T, Robertson S. Interteaching: Bringing behavioral education into the 21st century. . The Psychological Record. 2011;61(1):153-65.
65. Richmond A, Cranfield T, Cooper N. Study tips for medical students. BMJ. 2019;365:k663.
66. Croskerry P. Becoming Less Wrong (and More Rational) in Clinical Decisionmaking
. Ann Emerg Med. 2019;In press.

67. Bowen JL. Educational strategies to promote diagnostic reasoning. N Engl J Med. 2006;335:2217-25.
68. Pusic MV, Boutis K, Hatala R, Cook DA. Learning curves in health professions education. Acad Med. 2015;90(8):1034-42.
69. Cleary TJ, Durning SJ, Artino AR, Jr. Microanalytic Assessment of Self-Regulated Learning During Clinical Reasoning Tasks: Recent Developments and Next Steps. Acad Med. 2016;91(11):1516-21.
70. Lambe KA, O'Reilly G, Kelly BD, Curristan S. Dual-process cognitive interventions to enhance diagnostic reasoning: a systematic review. BMJ quality & safety. 2016.
71. Schmidt HG, Mamede S. How to improve the teaching of clinical reasoning: A narrative review and a proposal. Medical Education. 2015;49(10):961-73.
72. Krathwohl DR. A Revision of Bloom's Taxonomy: An Overview. Theory Into Practice. 2002;41(4):212-8.
73. Coderre S, Jenkins D, McLaughlin K. Qualitative differences in knowledge structure are associated with diagnostic performance in medical students. Advances in Health Sciences Education. 2009;14(5):677-84.

Tables and figures

Table 1 – Definition of knowledge

Knowledge term	Definition
'Knowledge'	Encompasses factual, conceptual, procedural and metacognitive knowledge(72)
'Low knowledge'	Generic low knowledge across all clinical domains
'Low clinical domain specific knowledge'	Low knowledge within a clinical domain, low problem specific knowledge(73) or low knowledge specific to the clinical case
'Inability to apply knowledge in a reasoning situation'	Has sufficient generic or clinical domain specific knowledge but lacks ability to apply this to a clinical reasoning case in a real or simulated clinical situation
'High clinical domain specific knowledge'	Sufficiently high knowledge with a clinical domain or high problem/clinical case specific knowledge
'Different levels of knowledge'	Differing generic levels of knowledge or problem specific knowledge between students in the same group

Figure 1 – PRISMA diagram

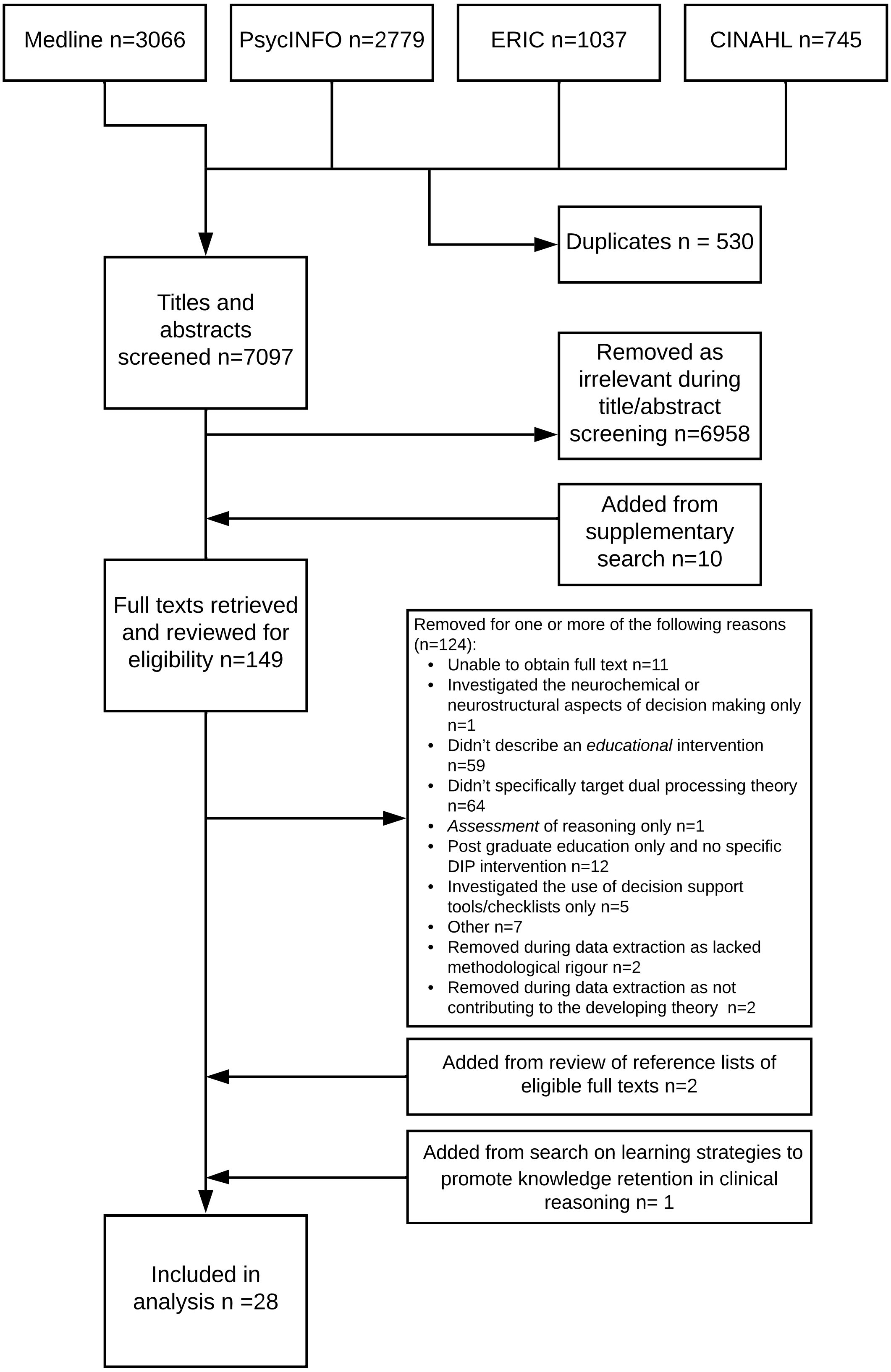

Figure 2 – Individual student contexts important to the outcomes of teaching

Figure 3 – CMOC's related to the context of low knowledge OR low case specific knowledge OR inability to apply knowledge in reasoning situation