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Self-Explanation, An Instructional Strategy to Foster Clinical Reasoning in Medical Students

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Abstract

Clinical reasoning is a critical and complex skill that medical students have to develop in the course of their training. Although research on medical expertise has successfully examined the different components of that skill, designing educational interventions that support the development of clinical reasoning in students remains a challenge for medical educators. The theory of medical expertise describes how students' medical knowledge develops and is progressively restructured during their training and in particular through clinical exposure to patient problems. Instructional strategies to foster students' learning from practice with clinical cases are scarce. This article describes the use of self-explanation as such a strategy. Self-explanation is an active learning technique of proven effectiveness in other domains which consists of having students explaining to themselves information on to-be-learned materials. The mechanisms through which self-explanation fosters learning are described. Self-explanation promotes knowledge development and revision of mental representations through elaboration on new information, organisation and integration of new knowledge into existing cognitive structures and monitoring of the learning process. Subsequently, the article shows how self-explanation has recently been investigated in medicine as an instructional strategy to support students' clinical reasoning. Available studies have demonstrated that students' diagnostic performance improves when they use self-explanation while solving clinical problems of a less familiar clinical topic. Unfamiliarity seems to trigger more self-explanations and to stimulate students to reactivate relevant biomedical knowledge, which could lead to the development of more coherent representations of diseases. The benefit of students' self-explanation is increased when it is combined with listening to residents' self-explanation examples and with prompts. The positive effect of self-explanation gets stronger when students' diagnostic performance is tested on far-transfer clinical cases, suggesting that deeper understanding and meaningful learning do occur. Self-explanation is a practical and inexpensive technique which could be incorporated into learning activities using clinical problems to promote diagnostic reasoning of medical students. Even though self-explanation is a promising learning technique, further studies are needed to explore other conditions that could maximise its benefit on learning clinical reasoning.

Keywords: Self-explanation; Clinical reasoning; Learning activity; Clinical education; Medical education

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1. Introduction

The present article discusses the use of self-explanation by medical students as a tool supporting the development of clinical reasoning. Self-explanation (SE) is a learning technique in which students explain to themselves pieces of a learning material for the purpose of improving their understanding. SE has been successfully used in several domains but only recently in medicine. Following a brief review of the theory of medical expertise describing how students' medical knowledge develops during their training, we will summarise some of the relevant literature on self-explanation outside the field of medical education to better understand how it supports knowledge construction. Then, we will briefly describe recently published studies on the use of self-explanation to foster clinical reasoning in medical students. Finally, we will discuss some implications for medical education and suggest issues for further research.

2. Clinical reasoning and the centrality of knowledge

Clinical reasoning can be broadly defined as the "intellectual activity done by the physician which synthesizes information obtained from the clinical situation, integrates it with previous knowledge and experience, and uses it for making diagnostic and management decisions".[1] Clinical reasoning applies, therefore, not only to diagnosis but also to decisions about management, investigations and treatment. Solving clinical problems involves, for example, history taking and physical examination, which are usually driven by hypotheses generated through clinical reasoning but require a variety of skills. However, in the present paper we will focus on the development of students' medical knowledge for diagnostic reasoning.

Since more than three decades, research on clinical reasoning has successfully explored and identified multiple facets of this complex skill.[2–7] While early research on clinical reasoning attempted to determine which reasoning *process* characterizes expert physicians, the centrality of knowledge in clinical reasoning has become clear, and it is presently acknowledged that expertise depends on the amount and richness of mental representations of diseases that doctors have in memory.[2,4,5] Experts' knowledge base is extensive and multidimensional; includes several types of knowledge, biomedical, clinical and experiential; and has an organisational structure that makes it usable in daily problem solving.[5] It allows clinicians when facing patients presenting with a specific clinical problem, to automatically and/or deliberately, activate the relevant diseases representations, generate hypothetical solutions, evaluate them and match the clinical data with expected findings.

The most prevalent theory of medical expertise explains it as the result of the development and restructuration of students' medical knowledge in the course of their training.[5,8,9] According to this theory, medical students go through transitory stages, each stage characterized by a different way in which knowledge is structured, kept in memory and used to solve clinical problems. The first stage is characterised by elaborate causal networks that explain causes and consequences of diseases in terms of underlying pathophysiological processes. With repeated application of this knowledge to patient problems, this format of knowledge organisation shifts to the second stage where these elaborate networks rich in biomedical knowledge becomes compiled into a limited number of summarizing concepts, clinical syndromes or diagnostic labels. This latter mechanism, called "knowledge encapsulation", is defined as the "subsuming or "packaging" of lower-level, detailed concepts and their inter-relations, under a smaller number of higher-level concepts with the same explanatory power".[5] Repeated exposure to clinical problems leads to the emergence of illness scripts, which characterize the third stage of development. Illness scripts are cognitive structures containing limited knowledge about causal mechanisms, because of previous encapsulation, but a large amount of clinically relevant information about a particular disease.[5,8,10] This clinical information comprises enabling conditions, i.e., conditions that predispose or set boundaries to the disease, the faults (brief description of the malfunction) and the consequences of the disease, such as symptoms, signs, and abnormal laboratory tests encountered in real patients with the disease. In the context of solving a clinical problem, relevant illness scripts are quickly activated in clinicians' mind, and search for the most appropriate one takes place by matching the elements of the script and the information of the particular patient. In this process of the script selection and verification, the characteristics of the patient are included and encoded as a practical example of the disease, a process called 'script instantiation'. Repetition of these processes again through clinical exposure leads to the fourth stage of the development in which clinician's formal knowledge is now enriched by experiential knowledge in the form of numerous instantiated scripts, which provide concrete examples of particular patients available for future problem solving.[5,10]

In many situations and mostly for routine cases, scripts activation occurs automatically, in a largely unconscious process, through pattern-recognition. Scripts verification to confirm or rule out diagnostic hypotheses then proceeds in a more deliberate or analytical way.[10] Even though illness scripts are the structures used mostly in daily problem solving, knowledge structures of previous stages remain accessible to clinicians and may be activated when they face complex or unusual cases. Encapsulated biomedical knowledge also provides coherence of the illness script by allowing expectations on acceptable and physiologically plausible values of its attributes and by explaining the relationships between them.[5,10]

So, in the course of their medical training, especially through exposure to patient problems, students are expected to construct, expand and reorganise their knowledge and to build up a large set of illness scripts, which gradually increases their ability to correctly diagnose patients' conditions.

Despite these significant advances in our understanding of how medical experts solve problems, a major challenge for current research is to determine how medical students can effectively develop this ability.[11] Practical educational implications of research on medical expertise were not explicitly considered until the last decade. Since then, however, knowledge derived from this research has led to many suggestions on how to support the development of students' clinical reasoning.[2–4,12–17] For instance, teaching approaches should emphasise acquiring domain-specific knowledge over general problem-solving strategies and should also support the integration of biomedical with clinical knowledge.[3–5,12] Exposure to patients' problems appears to be critical in the transformation of the medical knowledge structures.[13] Students should, therefore, be exposed early to a variety of cases or clinical examples that provide an accurate representation of the range of ways diseases occur.[3] Students should also be provided with many opportunities to practice and to engage in problem solving, to reflect and elaborate on patients' problems.[4,5,17] Even though these general recommendations provide guidance, specific instructional approaches or educational methods of proven effectiveness to help students learn more from practice with clinical problems remain scarce.[17]

Research in disciplines outside medical education such as cognitive psychology and educational psychology can provide theoretical frameworks and evidence-based learning strategies that could be combined with suggestions from research on medical expertise to design practical instructional approaches.[18,19] Self-explanation is an instructional strategy of proven effectiveness in other domains.[20,21] that could be transposed or applied to learning clinical reasoning. Before discussing how this could be done, we need to understand what is self-explanation and how it works.

3. The role of self-explanation in fostering learning

3.1. What is self-explanation?

Self-explanation is a learning technique first described by Chi[22] "that engages students in active learning and insures that the learners attend to the material in a meaningful way while monitoring their evolving understanding".[23] It involves having students generating for themselves explanations about pieces of information in a to-be-learned text or a to-be-solved problem.[20,22] The focus for the student is on trying to understand the material, to make sense of it personally. Self-explanation differs from explaining to others. In the latter case, the explanation tends to be more formal and with an implicit demand for coherence. Explanation directed to others may take into account the listener's knowledge and requires some monitoring of his/her comprehension. Moreover, most of the time, the explainer will focus on knowledge he or she understands most. In contrast, self-explanation, as the term implies, is self-generated and self-directed. Self-explanation statements are often fragmented and incomplete and tend to focus on what the learner does not understand. Self-explanation involves a special effort to deepen the learner's personal comprehension by trying to resolve misunderstandings.[22–23]

3.2. Is there evidence of self-explanation effectiveness to foster learning?

Since the seminal study by Chi[22] that showed self-explanation to be effective in teaching problem solving in physics for college students, the positive effect of the technique has been replicated in studies in other domains such as biology,[24] electricity and magnetism[20] and chess.[25] Self-explanation has been used with a variety of learning materials that include texts, problems and worked examples, which are examples providing the solution steps of the problem.[18,21] Self-explanation has also been used for a variety of learners ranging from elementary school learners to higher education students.[18] The self-explanation effect has also been demonstrated by using a wide range of assessment criterion from measures of memory, to comprehension, and to problem solving and on near as well as on far transfer tasks.[18] It has been observed that the benefit obtained from self-explanation increases when the problem at hand is complex.[20,24,26] In an study by Chi et al.[24] comparing 8th grade learners studying a human circulatory problem with or without SE, the learning improvement of the experimental group compared to the control was more remarkable (22.6% experimental group vs 12.5% control group) for the most difficult questions requiring application of knowledge to solve a new problem. Similarly, Wong et al.[26] compared 9th grade students trained to use self-explanation strategies while studying geometry theorem with a control group whose students used their usual studying techniques. Although both groups showed equal performance on domain-specific knowledge test, the self-explanation group outperform the control group on problem solving with in particular on far-transfer items, that is, problems that were substantially different from those used in the learning session.[26]

Given its broad applicability across different domains and the robustness of its effect, self-explanation can be described as a domain independent learning activity and be qualified as an evidence-based learning technique at least in experimental contexts.[18,20,27] However, despite the positive and promising results of this research, only a limited number of studies on the efficacy of self-explanation in representative educational contexts has been reported.[27,28,29]

3.3. What are the mechanisms underlying the self-explanation effect?

Self-explanation is based on an assumption of learning which is that “the acquisition of new knowledge requires the students to be actively involved in the construction of their own knowledge”.[20] According to the information-processing model which describes the architecture of human cognition,[19] schemas (i.e., mental representations of a task) construction takes place in the working memory when a student engages in making sense of the presented material. In doing so, he or she activates generative processes, namely selection, organisation and integration of new information to existing mental representations, which lead to knowledge building.[19,30] During learning, students can construct schemas by chunking elements together while solving problems, by integrating new information to existing schemas retrieved from the long-term memory but also by using available knowledge representations from other people or resources.[30] Learning medical knowledge for clinical reasoning involves building appropriate mental representations of diseases or illness scripts, which could be seen as a special type of schema, potentially developed by similar processes.

Self-explanation is a practical constructive activity that is assumed to foster the aforementioned generative processes and, consequently, knowledge restructuring.[20] What happens precisely during self-explanation? When students are asked to self-explain out loud, for example, while reading a text, they produce a variety of types of statements or self-explanation utterances which can be categorized as low or high quality statements according to their impact on learning.[20,23] Low quality statements comprise re-reading and paraphrases whereas inferences and monitoring statements represent high quality self-explanation utterances. Paraphrases are statements in which students only reiterate the text in their own words without adding new information. In contrast, inferences entail that students elaborate on, draw a conclusion or add information beyond what is said explicitly in the text. These types of statements may either fill information gaps, link elements of the text or integrate new information with prior knowledge. Inferences that referred to underlying domain principles (i.e., principle-based SE) have been particularly associated with successful learning.[31], Monitoring statements reflect otherwise comments where participants state that they do or do not understand, are confused, or raise questions about elements of the learning materials. Monitoring statements presumably help students focus learning on their specific needs. Inferences and monitoring statements are qualified as high quality statements since they reflect deep analyses of the material and support knowledge construction.[23] Finally, as self-explanation remarks reflect the student's ongoing understanding of the learning material, these comments are not necessarily complete, but often partial or even erroneous. However, if the learner, detecting these misunderstandings, then tries to resolve them, even these incorrect or erroneous statements may indeed promote learning.[20]

In sum, research on SE suggests that as a result of knowledge elaboration, organisation, and integration and monitoring, self-explanation supports knowledge restructuring, allowing the learner to revise and build a more coherent and integrated knowledge representation that facilitates transfer of learning.

3.4. How self-explanation can be supported in students?

Learning appears to correlate with the amount and quality of SE.[20,24,31] Chi et al.[24] compared the learning improvement of high vs low explainers based on the number of self-explanation inferences each student had generated. High explainers improved significantly more than low explainers in particular on the more difficult questions.[31] Investigating qualitatively self-explanation individual differences in university students working on probability calculation, Renkl showed that successful learners used more principled-based SE and tend to be more anticipative in reasoning.[31] Also, even though students may engage to some extent in 'covert' SE when reading a text or studying a material in silence, verbalisation of self-explanation out loud ('overt SE') seems necessary to produce the full self-explanation effect.[25]

Studies have shown that the degree to which learners spontaneously self-explain while studying examples or reading a text varies considerably among them.[23] However, students' SE can be supported by training prior to the learning task. For example, in the study by Wong et al.[26] the SE training procedure of the experimental group consisted of instructions on think aloud and self-explanation and listening to an audiotape of a model using three general questions that support SE: these questions were as follows: *What parts of this page are new to me? What does the statement mean? Is there anything I still don't understand?* In general, the benefits of self-explanation observed in the reported studies occurred with minimal instructions to students and most often little or no practice with SE before going through the learning or experimental task, suggesting that learners can be easily trained to self-explain.[23,18,32]

The application of prompts during the learning task is another intervention that fosters students' self-explanation. Prompts are specific instructions or requests that require learners to process the example or the content in a specific way.[33] Content-free prompts, which do not include any mention of the specific to-be-learned content, can be used with different materials and do not require any direct interaction with the teacher.[18] Even though studies on prompts are still limited, there is evidence that their use with SE enhances the effect of self-explanation.[24,26,33,34] Effective prompts presumably support the specific cognitive processes of the activity. 'Gap filling prompts' and 'mental-model revision prompts' are two types of effective prompts that have been studied with self-explanation.[29] For instance, a 'gap filling prompt' may require students to generate the principal justification and to focus on the underlying concepts (fostering generation of principle-based SE). Examples of this type of prompt would be: *What principle is being applied in this step? This choice is correct because…* On the other hand, 'mental-model revision prompts' help students identify discrepancies between their prior knowledge representation and the one provided in the learning material. Examples of this type of prompt would be: *How does it relate to what you already know? Does it help you gain more insight on how to solve the problem?*

Summing up, self-explanation is a research-supported strategy that has been shown to foster knowledge construction in a variety of domains. It may be a useful tool to put into practice educational recommendations emerging from research on medical expertise that advise students to get involved in deliberate problem solving when facing patients problems. This has been considered crucial to help medical students developing illness scripts and learning from clinical problems. Since self-explanation is known to support knowledge development and revision of mental representations, it is reasonable to think that, when transposed to clinical problem solving, this technique could help students develop their clinical reasoning.

4. Self-explanation to foster clinical reasoning in medical students

Recent studies have investigated the effect of medical students' self-explanation on clinical reasoning in clerkship and explored specific conditions that could optimise its effect. In 2011, Chamberland et al.[35] published what was, to our knowledge, the first study on SE and clinical reasoning, which investigated the benefit of using SE while diagnosing clinical cases for subsequent diagnostic performance of medical students. Since SE seems more effective on complex learning materials, this study also investigated if the effect of using SE would differ according to students' level of familiarity with the clinical topics. In the training phase, third-year medical students diagnosed a set of clinical cases, including four cases in a less familiar topic and four in a more familiar topic, either generating SE or not. Generating SE required explaining the reasons why the suggested diagnosis for the patient's problem was made. SE was, therefore, hypothesis-driven, as the process of history taking and physical examination uses to be, but students had to provide justifications for their hypotheses. The self-explanations were generated after minimal instructions, under controlled time, and no feedback on the quality or the content of SE was provided to students. One week later, in the assessment phase, all students diagnosed a set of new, more difficult cases, similarly distributed among the same more and less familiar topics. They provided a final diagnosis, used as a measurement of diagnostic accuracy, and a justified differential diagnosis, assumed as a measurement of diagnostic performance. Compared with students who had not used self-explanation during the learning phase, students who had diagnosed the cases with self-explanation showed significant better diagnostic performance scores (71% vs 55%). This positive effect of self-explanation on students' diagnoses was only found in cases of less familiar topics. In cases of conditions with which students were more familiar, no difference emerged.

The results of this study showed the benefit for medical students of using SE with clinical cases of less familiar topics but not for familiar ones, consistently with research on SE in other domains.[24,26] This benefit was observable one week after the intervention and on transfer tasks using different and more difficult cases, which reflects meaningful learning. Since the effect of SE presumably occurs through knowledge revision and restructuration, the authors suggested that students' SE may facilitate the construction of more coherent mental representations of the diseases, and this positive effect is likely to be more substantial when students are dealing with clinical problems in a less familiar area, for which their illness scripts may be less developed and therefore more subject to major revision.

In a second study, Chamberland et al.[36] investigated the types of knowledge used by students when self-explaining familiar and less familiar clinical cases and in particular the role of biomedical knowledge. They conducted a content analysis of SE verbal protocols produced by 7 randomly selected medical students during the previous study.[35] In total 56 verbal protocols (28 familiar and 28 less familiar) were segmented and coded using the following categories: paraphrases, biomedical inferences, clinical inferences, monitoring statements, and errors.[20,23] Biomedical inferences refer mainly to underlying pathophysiological mechanisms whereas clinical inferences point to attributes of people and their diseases, to signs and symptoms, and to relevant laboratory investigation.

The results showed that students provided overall more self-explanation segments when dealing with less familiar cases ($Mean=275.29$) compared to familiar ones ($Mean=248.71$, $p=.046$). While there was no significant difference in the total number of inferences, a significant interaction was found between familiarity and the type of inferences (biomedical vs. clinical). When self-explaining less familiar cases, students provided significantly more biomedical inferences than familiar cases.

These findings suggest that unfamiliarity acts as a trigger for students to engage in more active thinking; the greater diagnostic challenge apparently encourages them to generate more self-explanations, and eventually leads to better learning.[20,26] Even more interesting is the potential contribution of biomedical knowledge to the benefit of SE. Studies looking at the benefits of integrating relevant biomedical knowledge in the process of learning clinical reasoning in novice diagnosticians suggest that it may help students construct more coherent mental representations of diseases, increasing retention in the longer term and helping them to diagnose difficult cases.[12,37,38] Similarly, self-explanation when used while solving less familiar cases seems to activate students' biomedical knowledge, which could in turn help them create new links between biomedical and clinical knowledge and eventually construct a more coherent illness scripts or representation of a disease.

In two subsequent studies, Chamberland et al.[39,40] examined the added value for medical students of being exposed to self-explanation examples of clinical reasoning. Clinical reasoning is a complex and ill structured skill for which there are numerous possible paths to the solution. One may assume that listening to a colleague' self-explanation example dealing with the same clinical problem could provide some additional guidance for students. This assumption was first explored in a study that investigated the impact on students' clinical reasoning of combining students' SE with listening to peer or expert' SE examples.[39] In this two-phase experimental study, 53 third-year medical students were assigned to peer SE example, expert SE example or control group (no example). In the learning phase, all participants diagnosed a set of four clinical cases using SE and then either listened to a peer SE example or an expert SE example on the same case or were assigned to a control task. One week later, all students diagnosed the four same training cases and four transfer cases. The results showed that on training cases, students' diagnostic performance improved significantly but the main effect of group was not significant suggesting that students' SE mainly drives the observed effect. On transfer cases, there was no difference between the three groups. The absence of effect of adding SE peer or expert examples suggests that students did not engage in additional deep processing while listening to the examples. Discussing these results, the authors hypothesised that the level of expertise of the SE example vs the student might be important to consider: a peer SE example might be too similar and an expert SE example too different for students to learn from. Otherwise, without specific instructions on how to use the examples, it is possible that students did not actively process these examples. These ideas led to the subsequent study that investigated the use of SE examples of intermediate level of expertise (junior resident in internal medicine) and the addition of prompts while working with examples.[40] In this experimental study, 54 medical students were randomly assigned to three groups: the residents' SE group with prompts, the residents' SE without prompts and the control group. In the learning phase, all students diagnosed four clinical cases using SE. Then, one group listened to audio-recorded residents' SE examples with prompts, another group listened to residents' SE examples without prompts, while the control group did crosswords. One week later, in the assessment phase, all students solved four similar cases (near transfer cases) and four different cases (far transfer cases). Two types of prompts were incorporated into the residents' SE examples: the 'justification prompts' looking at the underlying pathophysiological mechanisms and the 'mental-model revision prompts' inviting students to compare their knowledge representation to the one presented in the example.[29]

Although all groups had significant improvement in diagnostic performance between the training phase and the one week later assessment on near-transfer cases, students who listened to the residents examples with prompts showed significantly better scores compared to the control group. On far transfer cases one week later, the impact got even stronger. The diagnostic accuracy and diagnostic performance scores of students who listened to residents' SE examples with prompts were respectively 20% and 17% higher than students in the control group. Again in this study, students' SE alone appears as an effective technique for learning clinical reasoning. Moreover, the impact is significantly increased when combined to residents' SE examples and especially with prompts. This suggests that junior residents' examples represent for clerks relevant models of clinical reasoning to learn from when made explicit by SE. It also suggests that the use of prompts helps students being an "active processor" of these SE examples.

In a recent study involving first-year medical students learning four clinical neurology topics, Larsen et al.[41] compared the effect on long-term retention of test-enhanced learning (TEL), self-explanation either alone or in combination with TEL and studying a review sheet. The main outcome measure was students' score on a free-recall application test six months later. The test was not measuring clinical reasoning or problem solving. The combination of both learning strategies produced the best performance, followed by TEL alone, self-explanation, and study of the review sheet. SE produced significant better performance than studying a review sheet. Interestingly, an interaction effect was observed between SE and topics suggesting that the usefulness of this technique may be related to the complexity or difficulty of the topic.[41] This study was the first one to assess the impact of SE in any domain for longer than few weeks.

It is interesting to note that outside self-explanation, recent studies have also reported positive results using other learning techniques and strategies that engage students in active learning for the purpose of supporting students' knowledge development and learning of clinical diagnosis. For instance, Mamede et al.[42,43] have shown that structured reflection on clinical cases by fourth year medical students was more effective to foster clinical diagnosis than generation of immediate or differential diagnoses. In these studies, structured reflection requested students to compare and contrast different illness scripts that represented alternative diagnoses for the clinical presentation displayed in the case. Using this procedure during practicing with cases was shown to improve students' diagnostic performance while solving new cases in the future. Indeed, comparing/contrasting scripts of diseases appears to be a useful tool also to learn physical examination integrated into a clinical reasoning task.[44,45] More recently, Baghdady et al.[46] showed that, in comparison with personal study, undergraduate dental students using test-enhanced learning on related basic science performed significantly better on a diagnostic accuracy test one week later.

5. Implications for medical education

Self-explanation appears to be an effective and practical way to engage students in active and "deliberate" problem solving, which supports the learning of clinical reasoning from practice with diagnosing clinical cases. SE can be used after minimal instructions, is rather inexpensive, does not need sophisticated technology and could then be readily implemented. Students' SE impacts positively on diagnostic performance even without specific feedback and could even be used by students without the need for direct clinical teachers' supervision. However, SE is not a panacea and its positive impact on learning seems to depend on the level of student's familiarity with the clinical topic. Hence, in designing activities using clinical cases with SE, teachers should pay attention in selecting cases that challenge students in order to maximise illness scripts enrichment and prior knowledge revision.

The results of these studies also add to the important role of biomedical knowledge while learning clinical reasoning with cases, at least for novice diagnosticians such as medical students at clerkship level. When self-explaining, it appears crucial to support students activating relevant biomedical knowledge and linking it with prior clinical knowledge or new information provided by the cases. It would then seem appropriate to include in students' SE training sessions or materials for clinical reasoning, specific instructions that reinforce activation of prior biomedical knowledge when needed, that is, either to resolve unclear or difficult issues in the case or to test the coherence of their explanations.

The aforementioned study on the use of residents' SE and prompts provides potentially interesting information on conditions to optimise learning from "natural" (or "non-didactically designed") examples of clinical reasoning available in the clinical settings. While recent studies suggest an important role of observing others for the development of clinical reasoning in workplace,[47,48] little is known on how to maximise learning from these models. Self-explanation might be a practical alternative to make ongoing clinical reasoning explicit and could have the potential to be also beneficial for the self-explainers themselves. Residents' examples of clinical reasoning made explicit by SE appear to be useful examples for students. However, in order to learn from SE examples, students have to get engaged cognitively for instance by self-explaining the case before, and actively process the examples with the use of prompts. The types of prompts used in the aforementioned study by Chamberland et al.[40] were general and content-free and could be applied to any clinical problem.

Available literature in other domains and the evidence now growing in medical education on the usefulness of self-explanation as well as other active learning techniques and strategies invite teachers to consider adding these techniques in their tool box when designing activities to foster clinical reasoning in medical students.

6. Issues for further research

Research on the use of SE in clinical teaching is in its first steps and much remains to be explored. Key issues, both from a practical and a theoretical perspective, can be highlighted. Regarding the former, the development and implementation of concrete learning activities that incorporate SE and SE examples in clinical training, in particular in the clerkship need further research. The exploration of other conditions that could maximise SE benefits on learning clinical reasoning also deserves more research. For instance, further studies could investigate the use of different learning materials closer to real patients such as students' reports of real clinical cases, standardized patients, virtual cases, or real patients. The number and variety of cases necessary to impact on learning with SE also need to be further examined. Otherwise, the addition of direct or delayed content-related and corrective feedback after SE and its impact on learning has not been specifically investigated. From a more theoretical perspective, further studies are also needed to better understand the impact of SE on specific knowledge structures as well as to shed more light on the mechanisms underlying the self-explanation effect on clinical reasoning. Although the authors of the reported studies hypothesised that students' improvement in diagnostic performance reflected activation of biomedical knowledge and linking with clinical knowledge leading to enrichment and revision of relevant knowledge, these changes were not directly examined. Finally, the use of self-explanation examples for learning clinical reasoning by students appears to be an interesting issue to further explore, for instance by looking at optimal conditions to learn from naturally occurring examples in clinical settings. Despite the high interest in medical education for the role of residents as teacher and models,[49] the contribution of residents as cognitive models for students' clinical reasoning development has not been specifically explored so far.

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