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# The effect of self-explanation of pathophysiological mechanisms of diseases on medical students' diagnostic performance

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**Abstract** Self-explanation while diagnosing clinical cases fosters medical students' diagnostic performance. In previous studies on self-explanation, students were free to self-explain any aspect of the case, and mostly clinical knowledge was used. Elaboration on knowledge of pathophysiological mechanisms of diseases has been largely unexplored in studies of strategies for teaching clinical reasoning. The purpose of this two-phase experiment was to investigate the effect of self-explanation of pathophysiology during practice with clinical cases on students' diagnostic performance. In the training phase, 39 4th-year medical students were randomly assigned to solve 6 criterion cases (3 of jaundice; 3 of chest pain), either self-explaining the pathophysiological mechanisms of the findings (n $=$ 20) or without self-explaining (n $=$ 19). One-week later, in the assessment phase, all students solved 6 new cases of the same syndromes. A repeated-measures analysis of variance on the mean diagnostic accuracy scores showed no significant main effects of study phase ($p = 0.34$) and experimental condition ($p = 0.10$) and no interaction effect ($p = 0.42$). A post hoc analysis found a significant interaction ($p = 0.022$) between study phase and syndrome type. Despite equal familiarity with jaundice and chest pain, the performance of the self-explanation group (but not of the non-self-explanation group) on jaundice cases significantly improved between training and assessment phases ($p = 0.035$) whereas no differences between phases emerged on chest pain cases. Self-explanation of pathophysiology did not improve students' diagnostic performance for all diseases. Apparently, the positive effect of this form of self-explanation on performance depends on

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the studied diseases sharing similar pathophysiological mechanisms, such as in the jaundice cases.

**Keywords** Self-explanation · Clinical reasoning · Educational strategies · Clinical education · Illness scripts · Medical education

## Introduction

Several factors can affect medical diagnostic performance, but diagnostic decision-making is considered to depend critically on physicians' clinical reasoning. The ability to reason through the set of features presented by a patient to generate an accurate diagnosis and recommend appropriate therapy defines physicians' performance in all levels of care. Not surprisingly, most medical schools attribute much importance to the development of their students' clinical reasoning. At every level of medical education, the acquisition of clinical reasoning skills appears as an essential learning goal (Norman 2005). Despite so important, empirical research on educational strategies to develop students' clinical reasoning competence is scarce. Several approaches have been proposed, but studies on their effectiveness are very limited (Eva 2004; Kassirer 2010).

The few strategies whose effectiveness have been investigated seem to share a common feature: they focus on knowledge acquisition, aiming at developing the cognitive representations of diseases that students have in memory (Chamberland et al. 2011; Ibiapina et al. 2014; Lee et al. 2010; Mamede et al. 2012, 2014; Papa et al. 1990). Different theoretical frameworks have been proposed to describe mental representations of medical knowledge, such as prototype-based models, schemas and scripts, and exemplars-based frameworks (for a review, see Norman 2005). The present study's conceptual framework is a well supported developmental theory of medical expertise (Schmidt et al. 1990). Research within this theoretical framework has shown that, in their trajectory from novice to experts, medical students go through several stages, each one characterized by a different way in which knowledge is organized in memory and used to solve clinical problems (Schmidt et al. 1990; Schmidt and Boshuizen 1993). In the beginning of their training, when students are exposed to knowledge of basic sciences (biomedical knowledge), they gradually construct in memory elaborate causal networks of knowledge explaining the causes and consequences of diseases on the basis of their pathophysiological mechanisms. Subsequently, as students start to apply this knowledge to deal with real or simulated clinical problems, a first change in the way how knowledge is organized in memory occurs. The elaborate networks of pathophysiological mechanisms are subsumed—or "encapsulated"—into high-level concepts or simplified causal models that explain signs and symptoms (Schmidt and Rikers 2007). Experts have in memory many encapsulated concepts or causal models and largely use them during the diagnostic process (Boshuizen and Schmidt 1992). As students continue to be exposed more and more to patients' problems, a second shift in knowledge representation takes place: the encapsulated knowledge is reorganized into a narrative-like structure, called "illness scripts". These illness scripts contain little (because encapsulated) knowledge of pathophysiological mechanisms of the particular disease but a wealth of clinical knowledge, such its signs, symptoms, and "enabling conditions", i.e. situational contexts and epidemiological data that indicate the conditions under which a disease is likely to occur (Charlin et al. 2007; Schmidt and Rikers

2007). As students gain clinical experience, examples of actual patients are also stored in mind, and illness scripts can therefore vary in their generality; whereas some consist of general prototypes of disease categories others are representations of previously seen patients.

Illness scripts, either in the form of examples of previous patients (Norman et al. 2007) or of disease categories (Charlin et al. 2007; Schmidt and Rikers 2007), are considered to play a critical role in the diagnostic process. Usually early in a clinical encounter, cues in the patient history activates in the doctors' mind one or a few relevant illness scripts, which leads to the generation of a diagnostic hypothesis. The illness script subsequently guides the doctor in his/her search for additional information to verify the appropriateness of this initial hypothesis by matching the patient's features with the elements of the illness script. Clinical competence, therefore, depends largely on developing in memory an arsenal of many and well-organized illness scripts. A remark is in order here. As illness scripts contain a wealth of clinical knowledge and little knowledge of basic sciences, the latter may appear as of little value in diagnostic reasoning. It should be noticed, however, that biomedical knowledge is embedded in clinical reasoning, and physicians may mobilize it to solve problems when needed (Verkoeijen et al. 2004). Indeed, experts possess a complex, multidimensional base of both formal and experiencial knowledge at their disposal to solve problems (Norman 2005).

This research on how students become experts has provided the basis to investigate strategies to teach clinical reasoning by fostering development of students' mental representations of diseases (Chamberland et al. 2011; Ibipiana et al. 2014; Lee et al. 2010; Mamede et al. 2012, 2014; Papa et al. 1990). One of the strategies that have proved effective to develop students' diagnostic competence is self-explanation (Chamberland et al. 2011; Chi et al. 1989). Self-explanation (SE) is defined as the act of generating explanations to oneself while studying a text or solving a problem. These explanations are remarks made by the students and directed to themselves about statements read in the to-be-learned material (Chi et al. 1989). Several cognitive processes are involved in self-explaining such as generation of inferences to figure out missing information, recognition of knowledge gaps with subsequent resolution, integration of new information to prior knowledge and monitoring defective knowledge (Calin-Jageman and Ratner 2005; Dunlosky et al. 2013; Patel et al. 2009; VanLehn and Jones 1993).

SE has been successfully used to foster learning in several domains (Bruin et al. 2007; Chi and VanLehn 1991; Chi et al. 1994; Leppink et al. 2012). In medicine, Chamberland et al. (2011, 2013, 2014) have conducted a series of studies using self-explanation as a strategy to teach clinical reasoning. In their first experimental study, medical students were requested, in the training phase, to solve clinical cases either generating self-explanations or not. Two sets of criterion clinical cases were used, consisting of less familiar topics and more familiar topics. One week later, in the assessment phase, students were requested to diagnose new, more difficult cases of the same topics, and their diagnostic performance was assessed. Students from the self-explanation condition demonstrated better diagnostic performance in the test than the control group, but only for those cases presenting diseases of the less familiar topics (Chamberland et al. 2011). Recently, the same authors showed that the addition of modelling (listening to an example of SE generated by residents) and prompts (specific questions) to students' self-explanation in the training phase improved students' diagnostic performance in the test relative to students who had learned with self-explanation alone (Chamberland et al. 2015).

It is important to notice that in the studies by Chamberland et al. SE was free, i.e. with no instruction on which aspects of the case students should explain. Consequently, students could focus, during SE, either on the underlying mechanisms of the clinical findings or in the clinical presentation itself. Whereas the former would imply using mostly biomedical knowledge, the latter would mobilize mostly clinical knowledge. A study by the same authors explored the types of knowledge that students used while self-explaining (Chamberland et al. 2013). A content analysis of protocols of self-explanations generated by the students demonstrated that less familiar cases trigger more self-explanation than more familiar ones. Moreover, the great majority of inferences made by the students consisted of clinical knowledge regardless case familiarity, but inferences referring to biomedical knowledge were three times more frequent when students self-explained less familiar than familiar cases. The authors suggested that self-explanation of less familiar cases compelled students to activate their biomedical knowledge, helping them to create new links between biomedical and clinical knowledge, eventually constructing a more coherent mental representation of diseases (Chamberland et al. 2013).

Other researchers have shown that approaches that engage students in elaboration on knowledge of causal mechanisms of diseases while solving clinical problems can foster learning of clinical diagnosis relative to approaches that focus on clinical findings alone (Woods et al. 2005; Woods 2007). While explaining the causal mechanisms of particular clinical findings during the diagnostic process, the authors argued, the students relate these findings with each other and with their underlying mechanisms, which presumably develops more stable and coherent mental representations of diseases (Woods et al. 2005; Woods 2007). It is reasonable to expect that a similar process may be triggered by SE while practicing with clinical cases as argued by Chamberland et al. (2013). To increase the possibility that SE has such an effect, SE should be guided by instructions that focus students' explanations on the pathophysiological mechanisms of diseases, otherwise they would tend to use largely clinical knowledge during SE (Chamberland et al. 2013).

The present study tested these ideas. We aimed at investigating whether SE guided by instructions requesting to explain the pathophysiological mechanisms of clinical presentations into-be-solved cases would foster medical students' diagnostic competence relative to providing the differential diagnosis for the cases. We conducted a two-phase experiment in which Year 4 medical students, during the training phase, were randomly assigned to solve eight clinical cases either using SE or not; one week later, all students diagnosed new cases of the same diseases. We hypothesized that students who had diagnosed the cases with SE during the training phase would have a better diagnostic performance in the one-week later test than the students who had not used SE.

## Methods

### Design

The study was an experiment consisting of two phases: a training phase and an assessment phase run one week later. In the training phase, students were asked to diagnose a set of eight clinical cases either using the self-explanation strategy (SE) oriented to pathophysiological mechanisms or without self-explanation (NS). In the assessment phase all students diagnosed the same set of 10 new clinical cases. Our primary measurement was students' diagnostic performance in the assessment phase. Figure 1 presents a diagram of the study design.

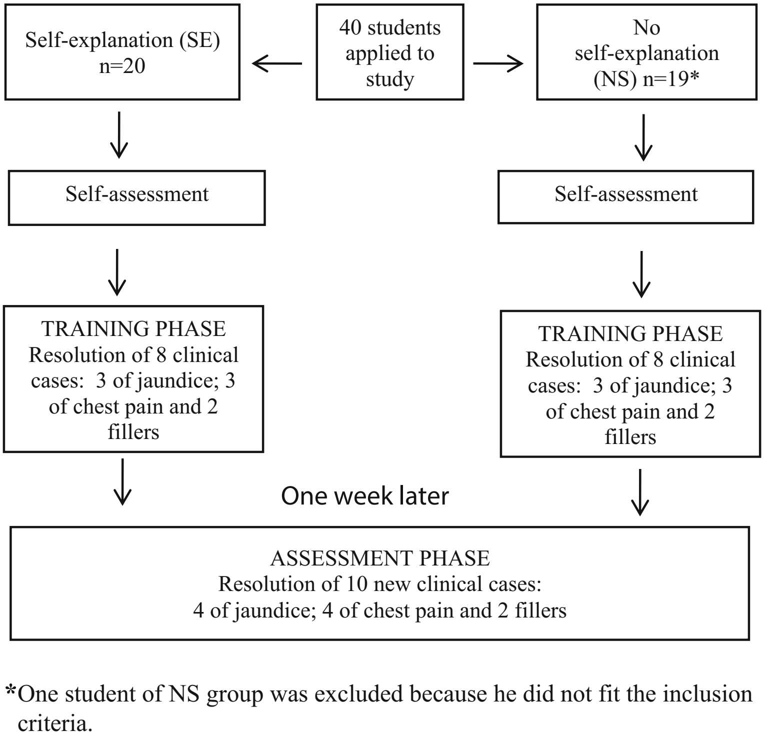

**Fig. 1** Diagram of the study design. One student of NS group was excluded because he did not fit the inclusion criteria

## Study participants

Participants were 39 medical students from the Medical School of the José do Rosario Vellano University (UNIFENAS), Belo Horizonte, Minas Gerais. All participants were in 4th year of the medical undergraduate programme, which has a 6-year problem-based learning curriculum. Students of the 4th year were chosen because at this point in their training they had already been exposed to theoretical knowledge about the clinical syndromes that would be used in the study, but had little clinical experience with them. Therefore, it was expected that these students had not yet developed and/or consolidated rich illness scripts of the diseases that would be used in the study. All 4th-year students were invited by the first author, during a seminar, to voluntarily participate in the study, and those who accepted were recruited as volunteers. The study was approved by the Research Ethics Committee of the university (decision letter # 176 896), and a written informed consent to use their data was obtained from all participants.

## Materials

For the training phase, a set of eight written clinical cases were prepared with three diseases with jaundice as the main clinical manifestation, three diseases with chest pain as the main manifestation and two fillers cases. For the assessment phase, another set of 10 new cases were prepared: four cases with jaundice as the chief complaint (three different cases of the same diagnoses studied in the training phase and one case with a disease also presenting with jaundice but that had not been studied in the training phase), four cases of chest pain (as for jaundice, three different cases of the same diagnoses studied in the training phase and one case of a new diagnosis of chest pain) and two different fillers cases (see "Appendix 1" for the list of the cases used in the study). Each case consisted of a short description of a patient, presented in a standardized format: it contained approximately 250 words, started with the clinical history, and subsequently described the findings of physical examination and laboratory tests. Three experts in internal medicine (A.S.M., J.M.P., R.M.D.F.) independently prepared the cases based on real patients. Subsequently, the cases were reviewed by the experts who discussed each case until they agreed, through a consensus model, that each case had one single most likely diagnosis, which was considered the correct diagnosis for the case. The cases for the assessment phase were intentionally prepared to be more difficult, displaying patients with atypical presentations of the disease and/or coexisting medical conditions (see "Appendix 2" for an example of one case used in the study).

The cases were presented in a booklet in a pre-established order, which was counterbalanced by preparing two different versions of the booklets to avoid order effect. Each booklet started by presenting the instructions about how to work with the cases in each experimental condition and an example case.

## Procedures

### *Assessment of previous knowledge and experience*

One week before the training phase, participants self-reported their level of knowledge and experience with each of the diseases that would be used in this study, which were embedded in a longer list of diseases. They did so by using a 5-point scale in which 1 = I have never studied this disease (for knowledge) or I have never seen a clinical case of this disease (for experience) and 5 = I have studied this disease frequently (for knowledge) or I have seen several clinical cases of this disease (for experience).

### *Training phase*

Participants were first randomly assigned to one of two groups: self-explanation (n = 20) and non-self-explanation (n = 19).

### *Procedures with the self-explanation (SE) group*

Firstly, all participants, gathered in a classroom, were informed by the first author about the procedures and how they would work in the training phase. Students were provided with a definition of self-explanation and listened to an audio recording, lasting 5 min, which showed an example of a student's self-explanation while solving a case that was not employed in the study. After that, the students were moved to individual rooms, where there was a computer with a software installed for recording their self-explanations (Audacity$^{®}$) and a teacher, responsible to ensure that participants would follow the previously given instructions. To standardize the teachers' performance, a step-by-step procedure to be followed during the session was designed, and all teachers participated in a training before the study, when the first author explained to them the study design and the procedures. During the training phase, one teacher coordinated the activities outside the individual rooms, controlling time to be spent on each case. In order to reduce an eventual influence of individual teachers' characteristics on students' performance, the teachers changed rooms after the student had completed each case, so each student always remained in the same room and solved cases with all teachers.

When authorized, participants started working with the first case. The teacher informed the students that they had 2 min to read the case and write down the most likely diagnosis for the case (referred to from now on as "initial diagnosis"). Subsequently, students were requested to explain aloud to themselves the pathophysiological mechanisms that underlie the patients' signs and symptoms, the findings of the physical examination and laboratory tests. Five minutes were allocated for this step, and students' explanations were recorded. After finishing their self-explanations, the students had 1 min to answer the following questions: (1) Does the explanation that you provided confirm your initial diagnosis? (check Yes or No); (2) If not, write down the new diagnosis that you would provide for this case; (3) Provide 2 alternative diagnoses for this case.

When the first case was completed, the students waited for the teacher to change rooms and, then, when authorized, started solving the next case, proceeding like that until all cases were completed. Students did not receive any feedback on the correctness of their diagnoses or the quality of their self-explanations.

### *Procedure with the non-self-explanation (NS) group*

Following Chamberland et al. (2011), students in the control group diagnosed the cases in a collective session. The students were gather in a classroom at the same time that the SE group was performing their task, so that contact between the groups could be prevented. A teacher previously trained on the procedures conducted this session. Participants were informed that they had 2 min to read each clinical case and then write down the most likely diagnosis for the case ("initial diagnosis"). Subsequently, they had 6 min to read the case again and answer the following questions: (1) Do you want to change the initial diagnosis? (2) If yes, then write down a new diagnosis for the case. (3) Provide two alternative diagnoses for the case. Before starting with the first case, they solved one example case, which was not used in the study. When permitted, the students start the resolution of the clinical cases. Time to work on each case (8 min) was controlled, and the students were only allowed to move to the next case when authorized by the teacher. No additional instruction about how to solve the cases was provided, and they did not receive any feedback on the quality of their responses.

The amount of time (8 min) allocated for working with each case, which was the same for both groups, was defined based on a study by Chamberland et al. (2011) and on a pilot conducted by authors with other students who did not participate in the study.

### *Assessment phase*

In this phase, all participants were brought together in a single classroom. Students were requested to read each of the ten new clinical cases and write down the most probable diagnosis and 2 alternative diagnoses, without any additional instructions. Time on each case was not registered. Participants were allowed 90 min to complete all the cases and could move on to next case freely.

## Data analysis

To assess the accuracy of students' responses, a spreadsheet was prepared for each clinical case which listed all diagnoses given by the participants in both study's phases. The spreadsheets were delivered to three experts in internal medicine who independently scored the diagnoses provided by students without being aware of the condition under which they were made. To score the students' initial and final diagnoses, we used a three-point score scale (1, 0.5 and 0), in which 1 was assigned when the diagnosis was correct, 0.5 when the diagnosis was partially correct, and 0 when the diagnosis was wrong. A diagnosis was considered correct if the core diagnosis of the case was cited (e.g. myocardial infarction in the case of myocardial infarction with ST segment elevation). When the core diagnosis was not informed, but one constituent element of the diagnosis was given, the diagnosis was evaluated as partially correct (e.g. ischemia in the case of myocardial infarction). When the diagnosis did not fit into one of these categories it was considered wrong. Scores assigned by evaluators for the diagnoses showed an agreement of 89.25% and discrepancies were solved by consensus.

Three variables were obtained from the participants' responses on each case: (1) the accuracy of the initial diagnosis provided for the case in the training phase; (2) the accuracy of the final diagnosis, i.e. the new diagnosis provided for the case in the training phase, after having self-explained (for the SE group) or have read again the case (for the NS group); (3) the accuracy of the initial diagnosis provided for the case in assessment phase. For each participant, a mean diagnostic accuracy score was computed for each aforementioned variable on the criterion cases. Mean scores were then computed for each variable for the SE and the NS groups.

To check for prior differences between groups in age and prior educational achievements, measured by grades in two blocks concerned with the diseases included in the study, we performed Student t-tests for independent samples. A Chi square test checked for eventual differences in gender between the groups. A repeated-measures analysis of variance (ANOVA) with experimental condition (self-explanation or non-self-explanation) as between-subjects factor and phase (training phase/initial diagnosis; training phase/final diagnosis; assessment phase/initial diagnosis) was performed on the mean diagnostic accuracy scores to test the hypothesis that self-explanation would foster learning relative to the non self-explanation approach. Significance level was set at $p < 0.05$ for all analyses. SPSS for Mac, version 20.0 was used for the analyses.

## Results

### Demographic and background characteristics of the study participants

Table 1 presents information on the background and demographic characteristics of the 39 participants according to the experimental condition. Both groups were similar in gender, mean age and mean grades in the curricular blocks related to the two clinical syndromes included in our study. Self-reported previous clinical experience and prior knowledge with the to-be-tested diseases were marginally higher in NS group.

**Table 1** Background and demographic characteristics of participants

| Descriptive measures | SE group (n = 20)<br>Mean (SD) | NS group (n = 19)<br>Mean (SD) | Significance<br>*p* |
|---|---|---|---|
| Age | 24.2 (4.6) | 23.3 (3.6) | 0.53[a] |
| Gender | | | |
| Male (%) | (35) | (36.8) | 0.91[b] |
| Female (%) | (65) | (63.2) | |
| Digestive syndromes grade | 80.1% (6.4) | 76.6% (6.4) | 0.10[a] |
| Cardiac syndromes grade | 80.6% (6.1) | 77.0% (11.1) | 0.21[a] |
| Self-reported experience | 1.57 (0.30) | 1.85(0.52) | 0.05[a] |
| Self-reported knowledge | 2.35 (0.32) | 2.83 (0.60) | 0.05[a] |

*SD* standard deviation, % percent

[a] Student's *t* test

[b] Chi square test

## Diagnostic performance

Table 2 displays the mean accuracy diagnostic scores obtained by students from each experimental condition in the training and the assessment phases. The repeated-measures ANOVA showed no significant main effect of performance moment ($F_{(2;74)} = 1.03$; $p = 0.34$). The main effect of experimental condition was also not significant ($F_{(1;37)} = 2{,}87$; $p = 0.10$), though a tendency emerged. This tendency was due to borderline differences in favour of the NS group in the training phase, both in the initial diagnosis ($t(37) = 1.93$, $p = 0.061$) and in the final diagnosis ($t(37) = 1.86$, $p = 0.071$), which did not remain in the assessment phase ($t(37) = 0.44$, $p = 0.66$). The interaction between performance moment and experimental condition was also not significant ($F_{(2;74)} = 0.88$; $p = 0.42$).

In an attempt to search for possible explanations for this unexpected lack of difference between the experimental conditions, we checked whether the type of clinical syndrome (jaundice or chest pain) could have acted as an intervening factor, influencing the results. We performed a post hoc repeated-measures analysis of variance (ANOVA) with experimental condition (SE or NS) as between-subjects factor, and performance moment (training phase/initial diagnosis; training phase/final diagnosis; assessment phase) and disease type (jaundice and chest pain) as within-subjects factors on the mean diagnostic accuracy scores. The main effects of performance moment, disease type, and experimental

**Table 2** Mean accuracy diagnostic score (range: 0–1) obtained by the two groups in the training phase (initial and final diagnoses) and assessment phase

| | SE group (n = 20) | | NS group (n = 19) | |
|---|---|---|---|---|
| | Mean score | SD | Mean score | SD |
| Training phase | | | | |
| Initial diagnosis | 0.45 | 0.19 | 0.55 | 0.15 |
| Final diagnosis | 0.50 | 0.18 | 0.59 | 0.14 |
| Assessment phase | 0.50 | 0.21 | 0.53 | 0.21 |

*SD* standard deviation

condition were not significant (all $p$ values >0.05). Regarding the interaction effects, the only significant interaction was between performance moment and disease type ($F_{(2;74)} = 4.48$; $p = 0.022$). Post hoc analyses to further explore this interaction showed that the mean diagnostic accuracy scores did not differ between the two groups neither on jaundice cases nor on chest pain cases in none of the study phases. However, differences were observed when the performance of the two groups across study phases were analysed. Whereas the performance of the SE group on the jaundice cases significantly improved between the training and the assessment phase ($t(19) = 2.27$, $p = 0.035$), the performance of the NS group was similar in these two phases, $t(18) = 0.79$, $p = 0.44$. Regarding the chest pain cases, no significant differences between the training and the assessment phase emerged in any of the groups (both $p$ values >0.20) (see Fig. 2).

## Discussion

The purpose of this study was to investigate the effect of engaging in self-explanation of the pathophysiological mechanisms of diseases while practicing with clinical cases on medical students' diagnostic competence. We hypothesized that students who had self-explained during the training phase would outperform those who had not when diagnosing new cases of the same syndromes in the assessment phase. The findings did not support this hypothesis. A marginally higher performance of the NS group in the training phase was not maintained in the assessment phase, which suggests that the SE group gained more from the learning exercise than the NS. However, the two groups did not statistically differ in diagnostic accuracy in the assessment phase.

Our findings are in contradiction with previous studies in medical education, which showed students who had used self-explanation during a training phase to perform significantly better in subsequent tests than those who had not self-explained (Chamberland

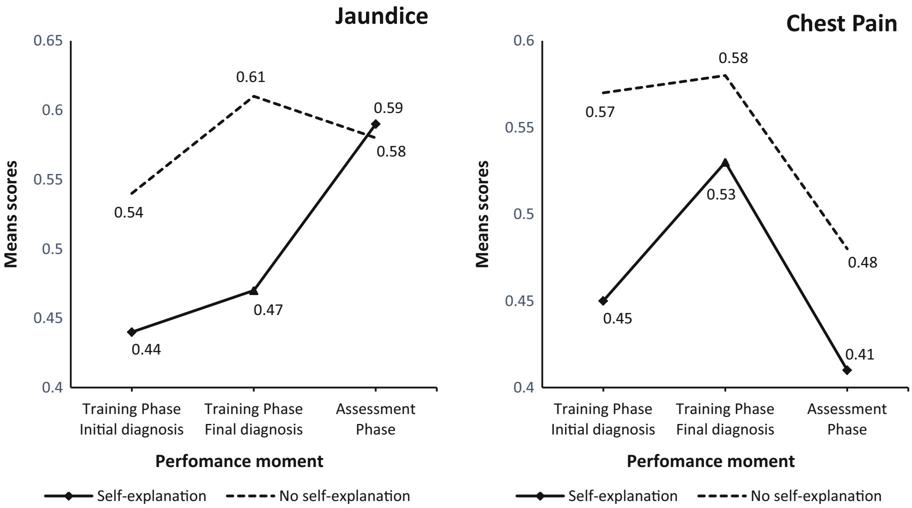

**Fig. 2** Mean accuracy diagnostic scores obtained by the SE (self-explanation) and the NS (no self-explanation) groups on jaundice and chest pain cases in the training (initial and final diagnosis) and in the assessment phase

et al. 2011, 2014, 2015; Larsen et al. 2013). Much care was taken in the design and implementation of the present study to ensure that the procedures that had proved successful in previous studies (Chamberland et al. 2011, 2014) would be strictly followed. What could therefore have prevented self-explanation to foster students' learning in our study?

A first tentative explanation relies on the level of students' familiarity with the diseases included in the study. Research on the use of self-explanation in learning both in medicine (Chamberland et al. 2011) and in other domains (Chi et al. 1994) have shown that self-explanation tends to be more beneficial when participants work on non-routine, complex problems. One possibility would be that the students in our study were already too familiar with the diseases that we used. However, the initial diagnostic accuracy scores obtained by the participants of our study are lower than the scores found in other studies (Chamberland et al. 2011, 2015; Larsen et al. 2013), which suggests that the cases were sufficiently complex for our students to have benefitted from self-explanation. Moreover, compared with the students from the NS group, the students from the SE group reported to have less familiarity with the diseases and obtained marginally lower scores in the learning phase, which again suggests that they could have gained from self-explanation.

A second explanation that can be raised refers to the focus of the self-explanation in the training phase. While in previous studies (Chamberland et al. 2011, 2014, 2015; Heitzmann et al. 2015; Larsen et al. 2013) students were requested to read the case and self-explain aloud freely, without being provided with a focus for their self-explanation, we requested students to explain specifically the underlying mechanisms of the clinical findings present in the case. Similarly to what has been shown to happen in other domains (Chi and Slotta 1993; VanLehn and Jones 1993), by compelling students to link pieces of information present in the cases and to integrate new information with existing knowledge, self-explanation was expected to lead to knowledge restructuring, thereby fostering the development of illness scripts. It is known, however, that self-explanation has to be repeated over time to enhance learning (Chi et al. 1994; Patel et al. 2009; Roy and Chi 2005). Practicing with more than one problem seems to be necessary. Self-explaining while diagnosing three cases of different diseases that shared the same chief complaints in the training phase should have allowed for such repeated practice. However, in a post hoc evaluation, we noticed an important difference between the two sets of diseases included in the study regarding their causal mechanisms. While self-explaining the three jaundice-related cases, students were repeatedly exposed to faults in the bilirubin's metabolism (because all diseases shared this basic underlying mechanism) and had, therefore, the opportunity to associate such faults with their consequences, i.e. the diseases' clinical presentation. However, this repeated exposure to similar causal processes could not occur when they explained the three chest-pain-related cases, because the diseases in these cases, though sharing the same chief complaint, had three entirely different mechanisms (coronary atherosclerosis with superimposed luminal thrombus for myocardial infarction; intimal tear in lining of the aorta for aortic dissection; changes in the barrier between the stomach and the esophagus for gastroesophageal reflux and inflammation of the pericardium for pericarditis).

A post hoc analysis conducted to check whether the similarity of the diseases' pathophysiological mechanisms could in fact have influenced the results provided some support for this explanation. The diagnostic performance of the SE group (but not that of the NS group) improved between the training and the assessment phase on the jaundice cases, which did not happen on the chest pain cases. This suggests that students who self-explained the underlying mechanisms of the diseases indeed learned more than students who did not provided that they had the opportunity to self-explain similar mechanisms repeatedly. However, other reasons could be evoked to account for the different patterns of performance for the two diseases. It would be possible that the cases of the two diseases were not equivalent in their level of complexity. Notice however that the post hoc analysis rather suggests that the jaundice cases and the chest pain cases were similarly complex to the students, in line with their self-reported familiarity with the diseases. Yet another possibility is that the different pattern of responses to the two diseases is merely circunstancial. As any post hoc analysis, ours should be taken with cautious, and its findings should be seen as triggers for further investigation.

Self-explanation has previously proved to foster medical students diagnostic competence (Chamberland et al. 2011, 2014, 2015; Heitzmann et al. 2015; Larsen et al. 2013). Our findings suggest, however, that there may be conditions that favour/hinder the production of this positive effect. It is to be questioned whether it is more effective to have students self-explaining in such way that they not only relate causal mechanisms to clinical findings, as they were requested to do in our study, but also match clinical findings to alternative diagnoses. Perhaps self-explanation focused on the causal mechanisms of diseases can only work (or work better) when the diseases studied share similar pathophysiological processes. Or may be it is more appropriate when students do not have yet acquired enough clinical knowledge that they can use and link to causal mechanisms in their explanations. Future research should aim at clarifying which format of self-explanation is more effective in each phase of training. A question emerging from this study is which format of self-explanation would work better to enhance learning of diseases that share similar pathophysiological mechanisms or those that have similar clinical presentations but entirely different underlying mechanisms.

## Conclusion

Summing up, our study showed that self-explanation focused on the causal mechanisms of the clinical findings present into-be-diagnosed cases failed in fostering students' diagnostic competence relative to the conventional approach of generating differential diagnosis. Alternative accounts for this finding may exist, and a reasonable one is the different patholophysiological mechanisms involved in one of the set of diseases studied. This format of self-explanation focused on pathophysiological processes may require the studied diseases to share similar causal mechanisms, a conjecture that has still to be investigated. Our study contributes to research on strategies to foster illness scripts formation by raising questions on conditions under which self-explanation is effective. The research questions that came out from our study can help foster investigation on a strategy that can play an important role in clinical teaching and about which there is still so much to be known.

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**Compliance with ethical standards**

**Conflict of interest** None.

## Appendix 1: Case diagnoses used in different phase of the study

| Training phase | Assessment phase |
|---|---|
| *Jaundice* | |
| Acute vital hepatitis | Acute vital hepatitis |
| Haemolysis | Haemolysis |
| Colelithiasis | Colelithiasis |
| | Pancreas tumor |
| *Chest pain* | |
| Myocardial infarction | Myocardial infarction |
| Aortic dissection | Aortic dissection |
| Gastroesophageal reflux | Gastroesophageal reflux |
| | Pericarditis |
| *Fillers* | |
| Pyelonephritis | Infectious mononucleosis |
| Pneumonia | Meningitis |

## Appendix 2: Example of a case used in the study

The patient was a 50-year-old female, married, lawyer, borned in São José de Almeida-MG and living in Belo Horizonte. She had one birth, one child and no abortion. She complains a severe abdominal colic pain located in the right upper quadrant and radiating to back. The pain started two weeks ago. She has made use of antispasmodic medication with partial improvement. Ten days ago she begans jaundice, dark urine, fecal hipocolia and itching. She denies nausea or vomiting. Reports loss weight (3 kg) in the last 3 months. She is social drinker: 2 cans of beer per week for 10 years. She denies smoking and previous surgeries. On physical examination the patient presented jaundice (3+/4), in a good general condition, mucous stained and hydrated, without edema. Her BMI was 28, temperature 37.3 °C, blood pressure 110/80 mmHg; pulse 78 bpm and respiratory rate 18/min. Cardiovascular system: good peripheral perfusion with large and full arterial pulses, regular heart rhythm times, without murmurs. Respiratory system: Normal expandability, physiological vesicular murmur, with no signs of breathing. Abdomen: peristaltic, flaccid, positive Murphy sign without pasta or visceromegaly.

| Lab tests results | Reference values | Lab tests results | Reference values |
|---|---|---|---|
| Hemoglobin: 14.8 g/dl | 12.0–16.0 g/dL | AST: 90 U/L | 15–40 U/L |
| MCV: 88 Fl | 80–100 Fl | ALT: 70 U/L | 5–35 U/L |
| MCH: 28 pg | 26–34 pg | Alkaline phosphatase: 740 U/L | 40–130 U/L |
| Leukocytes: 8800/μL | 4000–11,000/μL | Gamma GT: 277 U/L | 10–49 U/L |
| Neutrophilis: 77% | 45–75% | Total bilirubin: 18.2 mg/dL | 0.20–1.00 mg/dL |

| Lab tests results | Reference values | Lab tests results | Reference values |
|---|---|---|---|
| Lymphocytes: 23% | 22–40% | Direct bilirubin: 13.4 mg/dL | 0.00–0.20 mg/dL |
| Platelets: 344.000/µL | 150.000–450.000/µL | Indirect bilirubin: 4.8 mg/dL | 0.20–0.80 mg/dL |
| Reticulocytes: 1% | 0.5–1.5% | | |

## References

Boshuizen, H. P., & Schmidt, H. G. (1992). On the role of biomedical knowledge in clinical reasoning by experts, intermediates and novice. *Cognitive Science, 16,* 153–184.

Bruin, A. B., Rikers, R. M., & Schmidt, H. G. (2007). The effect of self-explanation and prediction on the development of principled understanding of chess in novices. *Contemporary Educational Psychology, 32*(2), 188–205. doi:10.1016/j.cedpsych.2006.01.001.

Calin-Jageman, R. J., & Ratner, H. H. (2005). The role of encoding in the self-explanation effect. *Cognition and Instruction, 23*(4), 523–543.

Chamberland, M., Mamede, S., St-Onge, C., Rivard, M.-A., Setrakian, J., Lévesque, A., et al. (2013). Students' self-explanations while solving unfamiliar cases: The role of biomedical knowledge. *Medical Education, 47,* 1109–1116. doi:10.1111/medu.12253.

Chamberland, M., Mamede, S., St-Onge, C., Setrakian, J., Bergeron, L., & Schmidt, H. (2015). Self-explanation in learning clinical reasoning: The added value of examples and prompts. *Medical Education, 49,* 193–202. doi:10.1111/medu.12623.

Chamberland, M., Mamede, S., St-Onge, C., Setrakian, J., & Schmidt, H. (2014). Does medical students' diagnostic performance improve by observing examples of self-explanation provided by peers or experts? *Advances in Health Sciences Education*. doi:10.1007/s10459-014-9576-7. **(Epub ahead of print)**.

Chamberland, M., St-Onge, C., Setrakian, J., Lanthier, L., Bergeron, L., Bourget, A., et al. (2011). The influence of medical students' self-explanations on diagnostic performance. *Medical Education, 45,* 688–695. doi:10.1111/j.1365-2923.2011.03933.x.

Charlin, B., Boshuizen, H. P., Custers, E. J., & Feltovich, P. J. (2007). Scripts and clinical reasoning. *Medical Education, 41,* 1178–1184. doi:10.1111/j.1365-2923.2007.02924.x.

Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13,* 145–182.

Chi, M. T., Leeuw, N. D., Chiu, M.-H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive Science, 18,* 439–477.

Chi, M. T., & Slotta, J. D. (1993). The ontological coherence of intuitive physics. *Cognition and Instruction, 10*(2–3), 249–260. doi:10.1080/07370008.1985.9649011.

Chi, M. T., & VanLehn, K. A. (1991). The content of physics self-explanations. *The Journal of the Learning Sciences, 1*(1), 69–105.

Dunlosky, J., Rawson, K. A., Marsh, E. J., Nathan, M. J., & Willingham, D. T. (2013). Improving students' learning with effective learning techniques: Promising directions from cognitive and educational psychology. *Psychological Science in the Public Interest, 14*(1), 4–58. doi:10.1177/1529100612453266.

Eva, K. W. (2004). What every teacher needs to know about clinical reasoning. *Medical Education, 39,* 98–106. doi:10.1111/j.1365-2929.2004.01972.x.

Heitzmann, N., Fischer, F., Kuhne-Eversmann, L., & Fischer, M. R. (2015). Enhancing diagnostic competence with self-explanation prompts and adaptable feedback. *Medical Education, 49,* 993–1003. doi:10.1111/medu.12778.

Ibiapina, C., Mamed, S., Moura, A., Elói-Santos, S., & Gog, T. V. (2014). Effects of free, cued and modelled reflection on medical students' diagnostic competence. *Medical Education, 48,* 796–805. doi:10.1111/medu.12435.

Kassirer, J. P. (2010). Teaching clinical reasoning: Case-based and coached. *Academic Medicine, 85*(7), 1118–1124.

Larsen, D. P., Butler, A. C., & Roediger, H. L., III. (2013). Comparative effects of test-enhanced learning and self-explanation on long-term retention. *Medical Education, 47,* 674–682. doi:10.1111/medu.12141.

Lee, A., Joynt, G. M., Lee, A. K., Ho, A. M., Groves, M., Vlantis, A. C., et al. (2010). Using illness scripts to teach clinical reasoning skills to medical students. *Family Medicine, 42*(4), 255–261.

Leppink, J., Broers, N., Imbos, T., Vleuten, C. V., & Berger, M. P. (2012). Self-explanation in the domain of statistics: An expertise reversal effect. *Higher Education, 63,* 771–785. doi:10.1007/s10734-011-9476-1.

Mamede, S., van Gog, T., Moura, A. S., Faria, R. M., Peixoto, J. M., Rikers, R. M., et al. (2012). Reflection as a strategy to foster medical students' acquisition of diagnostic competence. *Medical Education, 46,* 464–472. doi:10.1111/j.1365-2923.2012.04217.x.

Mamede, S., van Gog, T., Moura, A. S., Faria, R. M., Peixoto, J. M., & Schmidt, H. G. (2014). How can students' diagnostic competence benefit most from practice with clinical cases? The effects of structured reflection on future diagnosis of the same and novel diseases. *Academic Medicine, 89*(1), 121–127. doi:10.1097/ACM.0000000000000076.

Norman, G. (2005). Research in clinical reasoning: Past history and current trends. *Medical Education, 39,* 418–427. doi:10.1111/j.1365-2929.2005.02127.x.

Norman, G., Young, M., & Brooks, L. (2007). Non-analytical models of clinical reasoning: The role of experience. *Medical Education, 41*(12), 1140–1145. doi:10.1111/j.1365-2923.2007.02914.x.

Papa, F. J., Shores, J. H., & Meyer, S. (1990). Effects of pattern matching, patter discrimination, and experience in the development of diagnostic expertise. *Academic Medicine, 65*(9), S21–S22.

Patel, V. L., Yoskowitz, N. A., Arocha, J. F., & Shortliffe, E. H. (2009). Cognitive and learning sciences in biomedical and health instructional design: A review with lessons for biomedical informatics education. *Journal of Biomedical Informatics, 42,* 176–197. doi:10.1016/j.jbi.2008.12.002.

Roy, M., & Chi, M. (2005). The self-explanation principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 271–286). New York: Cambridge University Press.

Schmidt, H. G., & Boshuizen, H. P. (1993). On acquiring expertise in medicine. *Educational Psychology Review, 5*(3), 205–221. doi:10.1007/BF01323044.

Schmidt, H. G., Norman, G. R., & Boshuizen, H. A. (1990). A cognitive perspective on medical expertise: Theory and implications. *Academic Medicine, 65*(10), 611–621.

Schmidt, H. G., & Rikers, R. J. (2007). How expertise develops in medicine: Knowledge encapsulation and illness sripts formation. *Medical Education, 41,* 1133–1139. doi:10.1111/j.1365-2923.2007.02915x.

VanLehn, K. & Jones, R. M. (1993). What mediates the self-explanation effect? Knowledge gaps, schemas or analogies? In M. Polson (Ed.), *Proceedings of the Fifteenth Annual Conference of the Cognitive Science Society* (pp. 1034–1039). Hillsdale: Lawrence Erlbaum Associates.

Verkoeijen, P. P. J. L., Rikers, R. M .J .P., Schmidt, H. G., van de Wiel, M. W. J., & Kooman, J. P. (2004). Case representation by medical experts, intermediates and novices for laboratory data presented with or without a clinical context. *Medical Education, 38*, 617–627. doi:10.1046/j.1365-2923.2004.01797.x.

Woods, N. (2007). Science is fundamental: The role of biomedical knowledge in clinical reasoning. *Medical Education, 41*(12), 1173–1177. doi:10.1111/j.1365-2923.2007.02911.x.

Woods, N. N., Brooks, L. R., & Norman, G. R. (2005). The value of basic science in clinical diagnosis: Creating coherence among signs and symptoms. *Medical Education, 39,* 107–112. doi:10.1111/j.1365-2929.2004.02036.x.