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FEATURED ARTICLE

Teaching Clinical Reasoning: An Experiment Comparing the Effects of Small-group Hypothetico-deduction Versus Self-explanation

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Abstract

Introduction: **Research on the effectiveness of approaches for the teaching of clinical reasoning is scarce. A recent study showed hypothetico-deduction to be slightly more beneficial than self-explanation for students' diagnostic performance. An account for this difference was unclear. This study investigated whether hypothetico-deduction leads to consideration of more alternative diagnoses while practicing with cases, and whether its advantage over self-explanation remains when diseases slightly different from the ones previously studied are tested.**

Methods: **One-hundred thirty-nine 2nd-year students from a six-year medical school participated in a two-phase experiment. In the learning phase, they worked in small groups on five clinical vignettes of cardiovascular diseases by following different approaches depending on their experimental condition. Students under the self-explanation condition provided the most likely diagnosis and pathophysiological explanation for the clinical findings. Students under the hypothetico-deduction condition hypothesized about plausible diagnoses for clinical findings presented sequentially. In a one-week-later test, all students diagnosed eight cases of cardiovascular diseases with clinical presentations similar to the ones previously studied but different diagnoses.**

Results: **The hypothetico-deduction condition generated more alternative diagnoses in the learning phase than the self-explanation condition, $F(1,177) = 199.51$, $p = .001$, $\eta^2 = 0.53$; the effect size was large. A small difference in favour of hypothetico-deduction was observed in the proportion of accurate diagnoses: $F(1,138) = 4.08$, $p = .05$, $\eta^2 = 0.03$.**

Discussion: **Relative to self-explanation, hypothetico-deduction induced consideration of more alternative diagnoses during practice with cases. This may explain the slight benefit of hypothetico-deduction over self-explanation regarding students' diagnostic performance.**

Keywords: Clinical reasoning teaching, Diagnostic competence, Hypothetico-deduction, Self-explanation, Medical students

1. Introduction

The ability to make sound clinical judgments is a core component of physicians' competence, and the development of students' clinical reasoning is a major goal of medical education [1]. This acknowledgment of the importance of teaching clinical reasoning does not come together with an agreement on how to do this. Approaches for the teaching of clinical reasoning have been much discussed, but the little empirical evidence available on what works better and for whom provides teachers with little guidance for the choices they are to make [2–4].

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In recent years, teachers have increasingly faced the challenge of choosing appropriate instructional approaches to be employed in students' practice with simulated clinical cases. This challenge emerged because many schools now offer clinical reasoning courses which involve primarily practicing the diagnosis and/or management of simulated clinical cases. These courses appear to be a response to the recognition of the drawbacks of clinical clerkships as the locus for students to learn clinical reasoning. For example, clerkships hardly ensure exposure to a large variety of clinical problems or appropriate supervision [5,6]. In clinical reasoning courses with simulated cases, students have opportunity to practice with a large spectrum of clinical conditions while receiving appropriate supervision and feedback. However, although practice with clinical cases is a common characteristic of these courses, the instructional approach adopted varies substantially, as shown by a recent review of the literature [3]. As these approaches have rarely been empirically investigated, little is known about their effectiveness.

The present study is concerned with two approaches that have been used for the teaching of clinical reasoning: 'hypothetico-deduction' and self-explanation [3]. Hypothetico-deduction resembles physicians' diagnostic process in actual clinical practice. Information about the patient problem is provided to students in a sequential fashion. Little information is initially available, and as the student engages with the case, generates diagnostic hypotheses and requires information to verify the potential consequences of these hypotheses, after which additional information is provided. Conversely, for self-explanation the complete case information is presented from the start, and students are required to generate a diagnosis and explain the underlying mechanisms of the patient's symptoms. Self-explanation, a technique that has been largely used in other domains [7], is based on the assumption that reactivating previously learned knowledge and constructing the pathophysiological explanation would lead students to more clearly bringing together the signs and symptoms of the diseases, facilitating the diagnosis of new cases of the same diseases in the future [8–10].

Despite appearing to be the most prevalent approach used in clinical teaching [3,5], hypothetico-deduction was until recently not supported by any empirical evidence. Self-explanation, on the other hand, has been shown to increase medical students' diagnostic competence in several experimental studies [11–13]. In these experiments, cases were always presented to students individually, a condition that deviates from what is expected to happen in an actual medical curriculum, where students usually practice with peers. A recent experiment by our group compared the effects of hypothetico-deduction and self-explanation in small groups [13]. In a learning phase, second-year medical students, working in small groups, diagnosed a set of clinical cases either by using hypothetico-deduction or self-explanation. One week later, a test was administered that required students to diagnose a set of cases consisting of new exemplars of the clinical presentations studied in the learning phase. Diagnostic accuracy was measured. Students who engaged in hypothetico-deduction in the learning phase performed (slightly but significantly) better than the self-explanation group, contradicting our expectations.

Because self-explanation aims at restructuring and strengthening a learner's knowledge base, it can be expected to be beneficial for performance in a knowledge-based activity such as the diagnostic task. Indeed, this assumption has proved correct in several studies in which not only self-explanation [10,11] but also other strategies based on knowledge reconstruction [14,15] improved students' diagnostic performance. What could then explain the positive effect of hypothetico-deduction relative to self-explanation? We could not answer this question with the measurements available in our previous study. A tentative explanation may be that, different from self-explanation, hypothetico-deduction encouraged students to explicitly consider more than one diagnosis while working through the case. Because the cases solved in the learning and the test phase were not identical, students who hypothesized about several alternative diagnoses in the learning phase possibly also considered one or more diagnoses that returned in the test phase.

The present study examined this hypothesis. A design similar to the previous one was employed, but we now studied the contents of the learning phase to investigate whether hypothetico-deduction leads to consideration of more alternative diagnoses than self-explanation. In addition, we investigated whether our original findings could be replicated but focused on transfer by testing performance not on cases similar to the ones studied in the learning phase but on slightly different diseases.

2. Method

2.1. Design of the study

The study was an experiment with a learning phase and a diagnostic performance test administered 1 week after the learning phase.

2.1.1. Learning phase

Participants worked in small (around 6 students) groups to discuss and diagnose 5 clinical cases. They employed different procedures depending on the experimental condition to which they had been randomly assigned. Under the *hypothetico-deduction* condition, students were presented with case information in a sequential fashion and requested to provide tentative hypotheses, test these hypotheses as more information would be presented and discuss their findings with their peers in the group. Under the *self-explanation* condition, students received the whole case information and were asked to explain the signs and symptoms in terms of their underlying pathophysiological mechanisms in small groups and provide a diagnosis as well.

2.1.2. Test phase

In the test, all students were required to diagnose eight new clinical cases, representing diseases within the same (cardiovascular) system, but with different diagnoses.

2.2. Participants

All 188 male second-year students at King Saud bin Abdulaziz University medical college, in Riyadh, Saudi Arabia, a six-year medical school, were invited to participate in this study. We aimed at Year 2 students because, at this point in their training, they have been exposed to theoretical knowledge with regard to cardiology but have not yet encountered patients. Students were informed that their responses would be analyzed anonymously. One-hundred seventy-eight students accepted to participate. Written consent was obtained from all participants.

Ethical approval for the study was given by King Abdullah International Medical Research Center (KAIMRC) Riyadh, Saudi Arabia.

2.3. Materials

The study used two sets of different clinical cases, one for each phase (See Table 1). Each case consisted of a half-page description of a patient's

Table 1. Diagnoses of the cases used in the different phases of the study.

Learning phase	Test phase
Case 1.1 - Heart failure due to cor pulmonale	Case 2.1 - ST elevation myocardial infarction (STEMI)
Case 1.2 - Hypertension: secondary to coarctation of aorta	Case 2.2 - Unstable angina
Case 1.3 - Non-ST elevation myocardial infarction (NSTEMI)	Case 2.3 – Stable angina
Case 1.4 – Vasovagal syncope	Case 2.4 - Congestive heart failure (CHF) due to rheumatic mitral regurgitation
Case 1.5 - Non-cardiac chest pain due to costochondritis	Case 2.5 - Syncope due to complete heart block (CHB)
	Case 2.6 - Pre-syncope due to ventricular tachycardia (VT)
	Case 2.7 - Resistant hypertension due to renal artery stenosis
	Case 2.8 - Essential hypertension (HTN) with atrial fibrillation (AF)

Table 2. Example case (Heart failure due to cor pulmonale).

History

This is a 63-year old male who was admitted to the medical ward with lower limb swelling and abdominal distention that were not responding anymore to his usual medications. About 3 years ago he complained to his doctor about marked weight gain, abdominal distention and puffy feet, which all improved dramatically with medications which included "urine tablets". Previously he observed that leg swelling recurs shortly after missing the "urine tablets" for few days. Over the last few weeks the swelling has become troublesome and seems not responding to treatment despite doubling the doses. Patient gave a long history of chronic cough and wheezing that used to be treated with inhalers. Recently he was prescribed home oxygen and home nebulizers. Patient has been a heavy smoker since the age of 15 years. He quit smoking just few months ago, when his respiratory condition became worse.

Physical examination

Patient is in a semi-setting position, having a puffy face and shallow breathing. He is using the accessory muscles during breaths and can hardly complete a sentence without catching a breath. He is connected to an oxygen source via a face mask. O_2 saturation is 91%, BP is 119/62 mmHg, pulse is 112 (regular). Peripheries are warm and cyanosed with marked pitting edema in the legs. Both "a" and "v" waves of the JVP are visible and seen at the level of earlobe. Heart sounds are muffled with no audible murmurs. Chest percussion is hyper-resonant and lung auscultation revealed reduced air entry bilaterally with scattered rhonchi.

Investigations

Renal function: BUN: 9.5 mmol/l (normal range:3.5–7.2) and creatinine: 123 μmol/l (normal range: 60–110). CBC: Hb: 21 gm/dl (normal range:14–17), Htc: 0.49 (normal range:0.42–0.52). ABG: pH: 7.33 (normal range: 7.35–7.45), PCO_2: 56 mmHg (normal range: 35–45), PO_2: 64 mmHg (normal range:80–100), HCO_3: 35 mEq/l (normal range:22–26). CXR: normal heart size, clear lung fields, flat diaphragms, no effusions.

medical history, present complaints, findings of physical examination and of laboratory tests. Table 2 provides an example of a case used in the study. The cases were prepared for previous studies, based on real patients [10]. All came from the cardiovascular domain, as students had completed a cardiovascular system course three months before this study. In the learning phase, students used a response booklet in which they made notes.

2.4. Procedure

2.4.1. Learning phase

Prior to the start of the study, by using the list of students enrolled in the second year of the program, participants were, firstly, randomly assigned to work either under the self-explanation condition or the hypothetico-deduction condition, and, secondly, randomly subdivided in groups of six. Each group had a facilitator who was a member of the academic staff. All facilitators attended a 2-h training session aimed at familiarising them with the study and ensuring uniformity of the procedure. The facilitator's task was to take care that the procedure as described below was followed meticulously, without providing feedback or otherwise interfering with the learning. The to-be-diagnosed clinical cases were presented through PowerPoint slides in one of two randomized orders. Each student was also provided with a response booklet with blank pages on which he was asked to make notes.

In the self-explanation condition, once the case was presented, the students were given the following instructions: 1. Please read the case quickly. 2. Write down one or more diagnoses that come to mind. 3. Write down in bullet points which pathophysiological process may have caused the signs and symptoms in this case. 4. Now discuss your ideas about the pathophysiology of the case with you colleagues. 5. What is your final diagnosis? The first three steps were taken individually. On step 4, students had to explain to each other how the signs and symptoms in the case were produced. On step 5, they were to agree on a most likely diagnosis. After having reached an agreement, the next case was presented on screen. Students did not receive feedback. The steps taken individually required written responses, whereas the other steps demanded only verbal reporting.

In the hypothetico-deduction condition, each case was presented in sequential fashion: history, physical examination, and laboratory test results would appear only after students followed the relevant parts of the instructions: (For the history part) 1. Write down one or more diagnoses that come to mind while reading the history. 2. What further information would you need to test these diagnostic hypotheses? 3. Now discuss your ideas with you colleagues. (For the physical examination part) 4. Write down here one or more diagnoses that come to mind while reading the physical examination information. 5. What further information would you need to test these diagnostic hypotheses? 6. Now discuss your ideas with you colleagues (For the laboratory tests part) 7. Write down one or more diagnoses that come to mind while reading the laboratory data. 8. What is your final diagnosis? 9. Now discuss this conclusion with your colleagues. Steps 3, 6, and 9 required students to discuss ideas with their colleagues; the other steps were taken individually. As in the self-explanation condition, the steps taken individually required written responses, whereas the other steps demanded only verbal reporting. After completing a case, the next case was presented. Students were allowed to take as much time as they needed, but experimenters were instructed to spend no more than 10 min on each case and to record the total time needed to finalize the learning task. No significant differences in time emerged.

2.4.2. Test phase

One week after the learning phase, the students received, under examination conditions, a booklet with eight cases. Students were requested to read each case and write down the most likely diagnosis. At the end of the test phase, students were debriefed with regard to the study purpose.

2.5. Data analysis

The diagnoses provided in the learning phase were collated for each of the students, and the number of diagnoses, including or excluding repetitions, were counted.

The diagnosis provided by the participants to each case in the test phase was evaluated as correct, partially correct or incorrect, receiving scores of 1, 0.5, or 0 respectively. The diagnosis was considered correct whenever the core diagnosis of the case was provided (e.g., ‘stable angina’). When the core diagnosis was not given, but one component of the diagnosis was mentioned, the diagnosis was considered partially correct (e.g., ‘syncope’ rather than ‘syncope due to complete heart block”). When the participant's response did not fall into one of these categories, the diagnosis was considered incorrect. Two experts in internal medicine independently evaluated 20 participants' responses for each case. Responses had been previously transcribed from the booklets to excel sheets so that evaluators were not aware of the experimental condition under which the diagnoses had been provided. Their evaluations corresponded for 92% of the diagnoses; the remaining records were assessed by one of the experts.

For each participant, the total number of diagnoses mentioned in the response booklet, and the total number of diagnoses without repetitions, were counted. An ANOVA (significance level: 0.05) with experimental condition (self-explanation versus hypothetico-deduction condition) as between-subjects factor was conducted. The hypothesis tested was that students in the hypothetico-deduction condition would be producing significantly more diagnoses because their exercise was specifically aimed at the production of diagnoses.

Scores obtained in the test on the eight cases of cardiovascular diseases were averaged. An ANOVA (significance level: 0.05) with experimental condition (self-explanation versus hypothetico-deduction condition) as between-subjects factor was conducted. This analysis tested the hypothesis that hypothetico-deduction while solving clinical cases would lead to better diagnostic performance on the test.

3. Results

Table 3 presents the descriptive statistics of the number of diagnoses mentioned in the response booklet during the learning phase, with and without repetitions.

Due to an administrative error, more students ended up in the self-explanation condition. Random removal of 22 students did not affect the results and therefore the full dataset was analyzed. Univariate analyses of variance were conducted on the data displayed in Table 3 with experimental condition as independent variable and diagnosis count as the dependent variable. For mean number of diagnostic hypotheses mentioned, including repetitions: $F(1, 177) = 199.51$, $p = .001$, effect size eta squared equal to 0.53. For mean number of diagnostic hypotheses mentioned, without repetitions: $F(1, 177) = 109.57$, $p = .001$, effect size eta squared equal to 0.38. Both eta-squared values can be interpreted as the portion of variance explained by the treatment. Both can be considered sizable.

Table 4. Mean proportion of accurate diagnoses produced at test for both hypothetico-deduction and self-explanation condition. Ns and standard deviations included.

Treatment	N	Mean	Standard Deviation
Hypothetico- deduction	67	.39	.18
Self-explanation	72	.33	.16
Total	139	.36	.17

Table 4 displays the descriptive statistics of the proportion of accurate diagnoses produced at test.

Thirty-nine students who participated in the learning phase failed to show up for the test one week later; a dropout rate of 22%. Reasons were illness, having another appointment, or just forgotten. Using GPA-scores, we checked whether these absent students were different from those present. No significant differences between both groups were found. An ANOVA was conducted on the data displayed in Table 4: $F(1, 138) = 4.08$, $p = .05$, effect size eta squared equal to 0.03. These findings represent a significant but small difference in diagnostic accuracy favouring students under the hypothetico-deduction condition.

4. Discussion

The purpose of the present study was twofold. First, we investigated whether hypothetico-deduction during practice with clinical cases leads to consideration of a higher number of possible diagnoses relative to self-explanation. This was a tentative explanation for the finding from a previous experiment showing hypothetico-deduction to foster students' diagnostic performance relative to self-explanation. Second, we studied whether this higher effectiveness of hypothetico-deduction over self-explanation in fostering diagnostic performance could be replicated for diseases slightly different

Table 3. Mean number of diagnostic hypotheses mentioned per case during the learning phase with and without repetitions, for both hypothetico-deduction and self-explanation condition. Ns and standard deviations included.

	Treatment	N	Mean	Standard Deviation
Mean number of diagnostic hypotheses mentioned per case including repetitions	Hypothetico-deduction	78	5.42	1.52
	Self-explanation	100	2.95	.75
	Total	178	4.03	1.69
Mean number of diagnostic hypotheses mentioned per case without repetitions	Hypothetico-deduction	78	3.72	1.08
	Self-explanation	100	2.31	.70
	Total	178	2.93	1.12

(though in the same domain) from the ones studied in the learning phase. The results of our study of the contents of the learning phase support our tentative explanation. Students who engaged in hypothetico-deduction considered more diagnoses than the students from the self-explanation condition. Furthermore, relative to self-explanation hypothetico-deduction led to a slightly better diagnostic accuracy in the test which consisted of cases whose clinical presentation was similar to the ones studied in the learning phase but had different diagnoses.

A close look at the instructions provided to the two conditions can explain the findings referring to the number of diagnoses considered in the learning phase. Hypothetico-deduction required students to generate alternative diagnoses in three different moments: after disclosure of information on the patient's history, on physical examination and on diagnostic tests. This operationalization of hypothetico-deduction comes close to the format that has been employed in the teaching of clinical reasoning [3,16]. On the other hand, self-explanation, consistently with its use in research on learning in other domains and in medicine [8], required students to generate alternative diagnoses only at the start. Subsequently, they engaged in explaining the pathophysiological mechanisms underlying the patient's signs and symptoms without being encouraged to re-consider their initial hypotheses. It is not surprising therefore that students from the hypothetico-deduction condition raised more diagnoses than those from the self-explanation condition. The difference was substantial, particularly when repeated diagnoses were included.

This difference may have contributed to the slightly better performance of the hypothetico-deduction condition relative to the self-explanation condition in the test. This is so because generating a diagnosis and weighing the evidence supporting it in the learning phase would possibly strengthen the student's knowledge of this disease. For example, while working through the case of myocardial infarction in the learning phase, the student may have considered the diagnosis of unstable angina. Repeatedly weighing the extent to which the findings encountered in each of the three moments supported the tentative diagnosis of unstable angina may have contributed to strengthening knowledge of the disease represented in the student's memory. This would probably make the student who raised and analyzed the diagnosis of unstable angina slightly more apt to recognize the case of this disease in the test than a student who did not think about it in the learning phase. Notice that though self-explanation has probably led to restructure of knowledge about the diagnoses under consideration [8,10], this would apply for fewer diagnoses. On the other hand, for the students in the hypothetico-deduction condition, some knowledge restructuring, slight as it may have been, occurred for several diseases. The more diagnoses were examined in the learning phase, the higher the chance of having thought about one (or more) of the diagnoses that would be encountered in the test one week later. Because diagnostic performance depends critically on diseases knowledge as stored in memory [4,17,18], by inducing consideration of a larger number of diagnoses, hypothetico-deduction placed students in a slight advantage relative to the self-explanation group.

The superiority of hypothetico-deduction over self-explanation seems to contradict previous studies showing self-explanation in a learning phase to improve diagnostic performance in a later test [10,11,19]. It should be noticed, however, that the control group in these studies followed instructions very different from the hypothetico-deduction condition. The control group was not requested to think about different alternative diagnoses and match them with the case features but was requested only to give the best diagnosis for the case. This certainly entails much less elaboration and reconstruction of students' knowledge base than what may be expected to happen in hypothetico-deduction.

Our findings can be seen as diverging also from previous research showing the benefits of studying the causal mechanisms of diseases over studying associations between particular symptoms and these diseases [20,21]. Students who studied the causal mechanisms showed higher diagnostic performance in a test administered one week later in these studies. These results are seen as demonstrating the value of biomedical knowledge, which helps link specific clinical features together, setting meaningful relationships between them. With increased time lag between learning and test, students would rely more on these coherent relationships between features to make diagnoses than on consideration of isolated features [20,21]. The poorer performance of the self-explanation group in our experiment speaks against this conclusion from these studies. A methodological difference that might be taken into account is the material used in the learning phase. Whereas students in our experiment worked with clinical cases, the learning material in the aforementioned studies consisted of tables displaying the diseases and the probability that each feature is present. It cannot be excluded that clinical cases provided a more vivid, consequently more easily retained, picture of a disease. It can also be however, that the difference in favour of the hypothetico-deduction in our study, which was very small, would not survive the test of time and would vanish subsequently. By now, these are only conjectures that require further investigation.

A limitation of the present experiment emerges from the option to investigate the effect of the approaches when students worked in small groups with different facilitators. This choice approximates the experimental conditions to those that would be encountered in an actual clinical reasoning course but opens the door for the contents of the group discussion to influence the results. When students are tested individually, as it happened in previous research on self-explanation with medical students, much more control over exchange of information during the case work out is possible. Another issue possibly limiting the study is the students' low performance in the test. The diagnostic accuracy scores are substantially lower than the ones observed in the aforementioned research [10,21]. It can be questioned whether students in the self-explanation condition were actually able to activate sufficient biomedical knowledge to construct coherent pathophysiological explanations. Furthermore, it may well be that students who possess more prior knowledge of the diseases would benefit less from the elaboration that hypothetico-deduction induces, which may be low.

In summary, the present study showed hypothetico-deduction to induce consideration of a larger number of alternative diagnoses during practice with clinical cases relative to self-explanation. This may explain the slight benefit of hypothetico-deduction over self-explanation to students' diagnostic performance, which was replicated in this study for the diagnosis of diseases slightly different from the ones previously studied. Whether more knowledgeable students would benefit from hypothetico-deduction and whether its small advantage over self-explanation would vanish over time require further investigation.

Ethical approval

Ethical approval has been granted by the Ethical Review Board of King Saud bin Abdelaziz University of Health Sciences.

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