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Can Clinical Case Discussions foster clinical reasoning skills in undergraduate medical education? A randomised controlled trial

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RESEARCH PAPER

**Can Clinical Case Discussions foster clinical reasoning skills in
undergraduate medical education? A randomised controlled trial**

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Abstract

Objective: Fostering clinical reasoning is a mainstay of medical education. Based on the Clinicopathological Conferences, we propose a case-based peer teaching approach called Clinical Case Discussions (CCDs) to promote the respective skills in medical students. This study compares the effectiveness of different CCD formats with varying degrees of social interaction in fostering clinical reasoning.

Design, Setting, Participants: A single-center randomised controlled trial with a parallel design was conducted at a German university. The 106 study participants were stratified (age, gender, year of study, prior CCD participation, performance in a pre-test) and tested regarding their clinical reasoning skills right after CCD participation and two weeks later.

Intervention: Participants worked either within a live discussion group (Live-CCD), a group watching recordings of the live discussions (Video-CCD), or a group working with printed cases (Paper-Cases). The presentation of case information followed an admission-, discussion-, summary-sequence.

Primary and secondary outcome measures: Clinical reasoning skills were measured with a knowledge application test addressing the students' conceptual, strategic, and conditional knowledge. Additionally, subjective learning outcomes were assessed.

Results: With respect to learning outcomes, the Live-CCD group displayed the best results, followed by Video-CCD and Paper-Cases. No difference was found between Live-CCD and Video-CCD groups in the delayed post-test; both outperformed the Paper-Cases group. Regarding subjective learning outcomes, the Live-CCD received significantly better ratings than the other formats.

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4 **Conclusions:** This study demonstrates that the CCD approach is an effective and
5 sustainable clinical reasoning teaching resource for medical students. Subjective
6 learning outcomes underline the importance of learner (inter-)activity in the acquisition
7 of clinical reasoning skills in the context of case-based learning. Higher efficacy of
8 more interactive formats can be attributed to positive effects of collaborative learning.
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10 Future research should investigate how the Live-CCD format can further be improved
11 and how video-based CCDs can be enhanced through instructional support.
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21 **Article summary**

22 **Strengths and limitations of this study:**

- 23 • First empirical study on the implementation of Clinical Case Discussions in
24 undergraduate medical education.
- 25 • Comparison of Clinical Case Discussions with differing grades of social
26 interaction to determine their effectiveness on medical students' acquisition of
27 clinical reasoning skills by between-group analyses.
- 28 • Implementation of multidimensional and multilayered test instruments in a pre-,
29 post- and delayed post-test design to measure clinical reasoning skills by a
30 knowledge application test and self-assessment.
- 31 • The knowledge application test utilized in this study did not allow for a more in-
32 depth analysis of clinical reasoning skills (i.e., a distinction of conceptual,
33 strategic, and conditional knowledge).
- 34 • Despite the large sample size and strict randomisation the ubiquitous selection
35 bias in medical education when predominantly motivated students register
36 voluntarily for trials could have influenced the results of this study.
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Introduction

Curriculum developers face the challenge of implementing competence-oriented frameworks such as CanMEDS (Canada), the NKLM (Germany) or PROFILES (Switzerland), including the need to train clinical reasoning skills as a medical doctor's key competence.[1-3] As such, clinical reasoning skills are crucial not only for appropriate medical decision making, but also to avoid diagnostic errors and the associated harm for both patients and healthcare systems.[4]

Case-based learning has been proposed to foster clinical reasoning skills[5] and is well accepted amongst students.[6] Case-based learning found an early representation in Clinicopathological Conferences (CPC, first introduced by Cannon in 1900[7]) which are practiced until today. The Clinicopathological Conferences conducted at the Massachusetts General Hospital are published on a regular basis known as the *Case Records* series of the New England Journal of Medicine. In those CPCs the “medical mystery”[8] presented by the case under discussion calls readers to think about the possible diagnosis themselves, before it is finally disclosed at the last part of the CPC. Despite the absence of definitive evidence for efficacy as a teaching method, CPCs have widely been used in medical education since the early 20th century to foster clinical reasoning.[9-11] While these CPC-Case Records reaches lots of medical readers around the world, it has been criticised as being anachronistic with a diagnosing “star (i.e. the discussant), performing, acutely aware of being the center of attention”.[12]

Case-based learning formats are embedded in a context, which is known to promote learning better than providing facts in an abstract, non-contextual form.[13] Merseth proposed three essential elements for cases: “They are real, they rely on careful research and study; and they provide data for consideration and discussion by users”.[14]

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4 Compared to case vignettes, elaborated and authentic cases provide increased diagnostic
5 challenge, comprising an additional value for medical training.[15]
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8 However, due to their setup, CPCs are often a passive learning situation for participants,
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10 as they listen to the discussant laying out his or her clinical reasoning on the case under
11 discussion. According to the ICAP framework by Chi et al.,[16] teaching formats
12 increase their efficacy from passive < active < constructive < interactive learning
13 environments. Based on the ICAP model, any intervention that would lead to more
14 effective cognitive (i.e. constructive or interactive) learner activities should improve the
15 learning outcomes of that format. Especially when students interactively engage in
16 discussions among each other, learning is enhanced. Accordingly, case-based learning
17 has been found to be particularly beneficial in collaborative settings.[17] However,
18 another important aspect to consider in collaborative learning environments is the
19 potential for social loafing, i.e. mostly passive participation of students.[18] To foster
20 optimal learning effects, students should thus be encouraged to be interactively
21 engaged. One prerequisite to achieve self-guided learning in groups is a low threshold
22 for students to come forward with their questions and participate in ensuing
23 discussions.[19] To this end, peer teaching has been established as an effective tool to
24 stimulate discussions.[20] To make sure peer tutors are not overwhelmed in moderating
25 these discussions, the presence of an experienced clinician appears to be warranted[21]
26 in addition to a specific training of the tutors.
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46 Taken together, while traditional CPCs encompass some important dimensions of
47 effective case-based learning environments, they are not systematically aiming at
48 constructive or interactive learner activities that are known features of effective teaching
49 formats.[16,22] Therefore, we introduced Clinical Case Discussions (CCD) in
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4 undergraduate medical education to account for these features. We still use the Case
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6 Records of the Massachusetts General Hospital,[9] as these cases exemplify realistic
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8 patient encounters and fulfill the criteria for an interactive collaborative learning process
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10 as explained above. In the CCD approach, cases are presented only until the hospital
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12 admission of the patient, followed by an interactive discussion about possible diagnoses
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14 and diagnostic strategies. After all test results have been discussed, the actual diagnosis
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16 is disclosed and the pitfalls and take-home messages of the case are summarised.

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18 To investigate the effectiveness of the CCD approach in undergraduate medical
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20 education, we designed an intervention trial and assessed clinical reasoning skills in
21
22 medical students before and after *participating in live CCDs or being exposed* to video
23
24 recordings of live CCDs. We compared these formats and its effects on clinical
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26 reasoning with the more traditional approach of working through written cases. When
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28 carrying out this randomised trial, we hypothesised that participation in live CCD
29
30 sessions would lead to a higher increase of clinical reasoning skills than simply reading
31
32 the cases. To better understand possible effects of the CCD learning environment with
33
34 its social components on learning outcomes, participation in live CCDs as outlined
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36 above was additionally compared to the effects of watching videos of CCDs online.
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38 This comparison also seemed relevant from an economic point of view as video-
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40 streaming of lectures and seminars are prevalent at many institutions in higher
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42 education allowing for flexible and scalable access to learning materials.[23]
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49 **Methods**

50 **Study participants / Ethics**

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4 Initially, we recruited 106 volunteer medical students of XXXXX Medical Faculty.
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6 Participants were stratified by age, gender, year of study, prior CCD participation and
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8 performance in a knowledge application pre-test at T₀. They were then randomly
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10 assigned to one of the experimental groups and a total of 90 participants eventually
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12 completed the study, 31 of them were male and 59 female. They were 20 to 41 years old
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14 ($M = 23$; $SD = 2.97$) and in their first to eighth clinical semester ($M = 3.5$; $SD = 1.78$).
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16 The protocol for the trial was approved by the Institutional Ethics Review Board.
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18 Written informed consent was obtained from all study participants and they received a
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20 financial reimbursement of 50 Euros upon completion of the trial.
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25 **Patient and public involvement**

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27 No patients or public were involved in this research.
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32 **Clinical Case Discussions**

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34 In all experimental groups the intervention was based on the same three, independent
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36 internal medicine cases[24-26] which were worked through in an iterative approach in
37
38 different formats: (a) peer-moderated live case discussions in an interactive setting
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40 (Live-CCD, $n = 30$), (b) a single-learner format utilizing an interactive multimedia
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42 platform displaying video recordings of the live case discussions (Video-CCD, $n = 27$),
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44 and (c) a single-learner format in which the students worked with the original paper
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46 cases of the NEJM (Paper-Cases, $n = 33$). The cases were prepared in a way that
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48 participants in each format were exposed to the same case information.
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52 In all three groups cases were presented in a specified structured manner similar to the
53
54 original Clinicopathological Conferences (see Figure 1). In each format the students
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4 (“discussants”) had to fill out a form after the admission in which the case had to be
5 summarised and a list of clinical problems and working diagnoses had to be provided.
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7 Subsequently, between discussion and summary a second case-summary had to be
8 completed in which the final diagnostic test and the most likely diagnosis had to be
9 proposed.
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16 Insert Figure 1 about here

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20 In the Live-CCD group, the case presentation was prepared beforehand by a voluntary
21 discussant (“presenter”), who presented the facts in the admission (according to the
22 structure shown in Figure 1). Electronic slides and flipcharts were used to transport case
23 information. Original test results were revealed by the presenter during the discussion
24 only when requested by the group of students. Furthermore, the presenter summarised
25 the differential diagnosis, important pathophysiological features of the case at the end of
26 the session and provided a short take home message. A moderating medical student
27 (“moderator”) was trained in case presentation and facilitated a reasonable approach to
28 the patient encounter in close communication with the discussants. In the discussion the
29 moderator helped the students develop their diagnostic strategy by co-evaluating their
30 requested findings and the reasoning employed. Supervision of the correctness of
31 medical facts and the correct diagnostic approach were ultimately granted by a clinician
32 who could stop the discussion at any point when faulty reasoning was evident or
33 discussants explicitly requested the facilitation of an experienced physician. We varied
34 the staff between each Live-CCD to minimise effects of personal teacher characteristics.
35 Live sessions typically lasted 90 minutes and were recorded with multiple cameras.
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4 Students in the Video-CCD format worked on a single-learner multimedia workstation
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6 on which a video recording of the Live-CCD were displayed. These recordings also
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8 contained the electronic slide presentation from the Live-CCD and enabled
9
10 simultaneous observation of the discussion from multiple camera angles. Participants
11
12 could pause and partially skip the videos.
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14 In the Paper-Cases group participants received the case information of each CCD
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16 section sequentially (i.e. admission, discussion, summary) in a print format. In both
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18 single-learner formats students could choose their personal working speed with no time
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20 limit. In each of the three formats full access to the internet was permitted for additional
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22 information.
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27 **Study design**

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29 We conducted a single-center randomised controlled trial consisting of a total of five
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31 course sessions with a parallel design (see Figure 2): In an introductory session (T_0)
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33 participants were introduced to the principles of the CCD approach and the sequence of
34
35 this trial. In the experimental phase, participants attended three weekly interventional
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37 course sessions of 90 minutes each in one of the three aforementioned groups with the
38
39 respective CCD formats. T_1 testing was carried out at the end of the last experimental
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41 course session. Two weeks after completion of the interventional courses a delayed
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43 knowledge application post-test (T_2) was conducted.
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Instruments

Learning outcomes with respect to clinical reasoning were measured with a knowledge application test that consisted of 29 items (i.e. a maximum of 29 points could be achieved). The test was to be filled out within 45 minutes and comprised multiple choice items, key feature problems and problem-solving tasks,[27] addressing the conceptual, strategic, and conditional knowledge of the participants. Overall test reliability was satisfactory (Cronbach's $\alpha = .71$).

Subjective learning outcomes were measured at T_1 with a short questionnaire consisting of 9 items (e.g. "I learned a lot during the CCD course", "The CCD course increased my learning " or "I recommend the implementation of the CCD teaching format into the curriculum"). Participants were asked to rate these items on a Likert scale ranging from 1 (I don't agree) to 5 (I fully agree). Reliability of the corresponding scale was good (Cronbach's $\alpha = .95$). Additionally, study participants were asked to share their views on positive and negative aspects of the respective training format through open items at the end of the questionnaire.

Statistical Analysis

The required sample size (N = 128) was estimated to detect medium effect sizes with a power of 80% and a significance level of $\alpha = .05$. For between-group analyses, ANOVAs were conducted with *post-hoc* Bonferroni tests for multiple comparisons.

Results

Preliminary analyses

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4 Prior knowledge (T₀) did not differ across groups, with $M = 5.34$; $SD = 1.93$ for Live-
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6 CCD, $M = 4.76$; $SD = 1.90$ for Video-CCD, and $M = 5.76$; $SD = 2.24$ for Paper-Cases
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8 with $F(2,87) = 1.78$, $p = .174$ (n.s.). Gender distribution was skewed between the
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10 experimental groups due to drop-out, but did not affect the learning outcomes as male
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12 students ($M = 12.33$; $SD = 4.25$) and female students ($M = 10.80$; $SD = 3.50$) did not
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14 differ significantly in the knowledge application post-test, $F(2,88) = 3.37$, $p = .07$ (n.s.).
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19 **Effects of the CCD format on learning outcomes related to Clinical Reasoning**

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21 Experimental groups differed significantly with respect to the knowledge application
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23 post-test (see Table 1), $F(2,87) = 27.07$, $p = .000$, partial $\eta^2 = .384$. The Live-CCD
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25 group ($M = 14.10$; $SD = 3.32$) outperformed both the Video-CCD ($M = 11.69$; $SD =$
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27 3.34) and the Paper-Cases group ($M = 8.5$; $SD = 2.44$). Post hoc Bonferroni tests
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29 revealed significant differences between Live-CCD and Video-CCD ($p = .011$) as well
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31 as the Paper-Cases group ($p = .000$). The difference in the knowledge application post-
32
33 test between Video-CCD and the Paper-Cases group was also significant ($p = .000$).
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36 Two weeks after course completion, the effect of the teaching format was still found in
37
38 a delayed knowledge application post-test, $F(2,87) = 30.91$, $p = .000$, partial $\eta^2 = .415$.
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40 Both Live-CCD ($M = 13.36$; $SD = 3.23$) and the Video-CCD ($M = 11.84$; $SD = 2.92$)
41
42 outperformed the Paper-Cases group ($M = 7.89$; $SD = 2.41$). Post hoc Bonferroni tests
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44 revealed significant differences between the Live-CCD and Paper-Cases group ($p =$
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46 $.000$) as well as between the Video-CCD and Paper-Cases group ($p = .000$). However,
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48 the difference between Live-CCD and Video-CCD was not significant in the delayed
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50 knowledge application post-test ($p = .146$).
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Table 1. Overview of the findings of the study.

	Teaching format					
	Live-CCD		Video-CCD		Paper-Cases	
	M	(SD)	M	(SD)	M	(SD)
Knowledge application pre-test	5.34	(1.92)	4.76	(1.90)	5.76	(2.24)
	<i>n</i> = 30		<i>n</i> = 27		<i>n</i> = 33	
Knowledge application post-test	14.10	(3.32)	11.68	(3.34)	8.50	(2.44)
	<i>n</i> = 30		<i>n</i> = 27		<i>n</i> = 33	
Delayed knowledge application post-test	13.36	(3.23)	11.84	(2.92)	7.89	(2.41)
	<i>n</i> = 30		<i>n</i> = 27		<i>n</i> = 33	
Subjective learning outcomes	4.20	(.63)	3.18	(1.24)	3.00	(.99)
	<i>n</i> = 30		<i>n</i> = 27		<i>n</i> = 31	

Effects of the CCD format on subjective learning outcomes

Experimental groups differed significantly with respect to subjective learning outcomes (see Table 1), $F(2,85) = 13.16$, $p = .000$, partial $\eta^2 = .236$. Participants of the Live-CCD group ($M = 4.20$; $SD = .63$) assigned better ratings to their course format than participants in the Video-CCD group ($M = 3.18$; $SD = 1.24$) and the Paper-Cases group ($M = 3.0$; $SD = .99$). Post hoc Bonferroni tests showed that the Live-CCD differed from the Video-CCD ($p = .001$) and the Paper-Cases group ($p = .000$) in this regard. An additional Duncan post-hoc test confirmed that the Video-CCD and the Paper-Cases group did not differ from each other in this regard ($p = .48$).

To investigate the relations between the subjective assessment and the knowledge application tests applied at the end and two weeks after the course, we calculated correlations between the different outcome measures. Subjective learning outcomes correlated on a medium level with both the knowledge application post-test ($r = .343$, n

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4 = 88, $p = .001$) and the delayed knowledge application post-test ($r = .339$, $n = 88$, $p =$
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6 .001).

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8 In the Live-CCD group, 83% of the students were in favour of implementing routine
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10 Live-CCD into the medical curriculum. Only 45% and 31% of students from the Video-
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12 CCD and Paper-Cases groups voted for an implementation of their respective course in
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14 the curriculum. With respect to the open items from the subjective learning outcomes
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16 questionnaire, participants from all groups praised the quality of the cases. Participants
17
18 from the Live-CCD group particularly valued their course format for providing an
19
20 opportunity to practice “diagnostic thinking” and the “focus on practice elements”. They
21
22 also mentioned that “you can look up theoretical knowledge, but you can’t look up
23
24 applied knowledge”. Students in the Video-CCD group, on the other hand, praised
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26 features of the digital learning environment as they could “pause, reflect, or quickly do a
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28 Google search” when watching the case discussions. However, they also criticised it
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30 was not possible for them to “participate in a more active way”.
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37 **Discussion**

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39 This randomised controlled study shows that even relatively short CCD interventions
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41 can lead to improved and sustainable learning outcomes with respect to clinical
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43 reasoning. This provides evidence that the CCD approach, which is based on
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45 Clinicopathological Conferences, is an effective teaching resource to foster clinical
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47 reasoning skills in medical students. We had hypothesised that a more interactive course
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49 format would result in an improvement of clinical reasoning skills when compared with
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51 less interactive formats. Results show that the Live-CCD indeed leads to the highest
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53 learning outcomes in medical students compared to less interactive formats. Consistent
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4 with our hypothesis, clinical reasoning skills, as measured with our knowledge
5 application test, had the highest gain in the Live-CCD group. These positive effects of
6 the CCD teaching format on clinical reasoning skills proved sustainable as shown by the
7 results in the delayed knowledge application post-test. Overall, these results are in line
8 with a recently published study on diagnostic reasoning[28] where students who worked
9 in pairs were more accurate in their diagnosis than individual students despite having
10 comparable knowledge. Collaborative clinical reasoning has thus far been
11 underrepresented in the literature, yet seems to solve many of the educational problems
12 regarding diagnostic errors.[29]

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23 The significant difference between the Live-CCD and the Video-CCD group can be
24 explained by the findings of a meta-analysis that showed technology-assisted single-
25 person learning to be inferior to group learning because of the decreased social
26 interaction.[30] However, it is important to note that two weeks after the course,
27 participants of the Live-CCD and Video-CCD groups did not differ significantly
28 anymore while both groups still clearly outperformed the Paper-Case group. In other
29 words, watching a video of the live case discussion was found to be more beneficial for
30 learners regarding their clinical reasoning skills than just reading the printed cases.
31 Subjective learning outcomes suggest that students prefer the live discussion over the
32 other formats and were linked to their performance in the knowledge application test.
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Additional qualitative data from the open item answers suggests that the Live-CCD
format supported students in performing clinical reasoning and that the active
discussion of cases was particularly valued by the students.

Generalisability

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4 The conclusions of this study are applicable to a broader audience of medical students.
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6 The CCD approach and its respective formats can easily be implemented in routine
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8 medical education. Peer teaching courses hold the promise of being more easy to install
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10 and more easy to staff than courses led by faculty. The study population consisting of
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12 students with heterogeneous levels of clinical experience implies that the CCD is an
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14 effective teaching format not only for students at the beginning of their clinical career
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16 but also for intermediate students. On the other hand, generalisability is potentially
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18 limited as only students from one medical school participated in our study.
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23 **Limitations of the study**

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25 There are certain limitations of this study that have to be addressed: One important
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27 limitation is the single-centre nature of this study and the relatively small sample size.
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29 Before the CCD approach can be implemented on a larger scale, a validation of our
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31 findings is therefore required. Caution is clearly warranted with the effect sizes shown
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33 in this trial, as it has been shown that effect sizes of learning intervention trials tend to
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35 be inflated compared to the effectiveness of the intervention when used in routine
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37 education.[31] Against this backdrop, we suggest replication to further validate the
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39 results found in this study and strengthen the outlined implications.
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45 **Implications for policy makers / Future research questions**

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47 Based on our findings, the CCD approach is a useful asset for medical educators to
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49 widen the range of clinical reasoning teaching tools. Live-CCD can thus be seen as a
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51 prime candidate for routine implementation in clinical reasoning curricula. Future
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53 research should aim to identify which Live-CCD elements (i.e. the roles, case contents,
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4 or the course structure) contribute in which way to the improvement of clinical
5 reasoning skills in medical students. Regarding the Video-CCD, means of instructional
6 support to increase the effectiveness and interactivity of the video-based format should
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8 be investigated in an attempt to exploit its full potential.
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14
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46 **Competing Interests**

47
48 Marc Weidenbusch declares to have no conflict of interest.

49
50 Benedikt Lenzer declares to have no conflict of interest.

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52 Maximilian Sailer declares to have no conflict of interest.
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4 Christian Strobel declares to have no conflict of interest.

5
6 Raphael Kunisch declares to have no conflict of interest.

7
8 Jan Kiesewetter declares to have no conflict of interest.

9
10 Martin R. Fischer declares to have no conflict of interest.

11
12 Jan M. Zottmann declares to have no conflict of interest.

13 14 15 16 17 **Author contributions**

18
19 MW, BL, MF and JZ planned the study.

20
21 MW, BL and CS were responsible for data acquisition.

22
23 MW, BL, RK, JK, JZ and MS analysed and interpreted the data.

24
25 MW, BL and JZ drafted the manuscript, all authors contributed significant intellectual
26
27 content and all authors gave final approval of the version to be published.

28 29 30 31 32 **Data sharing statement**

33
34 Dataset and detailed information about the CCD formats is available upon request.

35 36 37 38 39 **References**

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Figure legends

Figure 1: Live-CCD Structure. CCD sessions are divided into three parts: In the *admission* part the presenting student shows the discussants his prepared slides (based on the original NEJM-case record), after which the group has to agree on an assessment of the patient under discussion. In the interactive *discussion* part the students prioritise the medical problems, link them to possible etiologies and order tests to further corroborate or discard differential diagnoses. After all the tests that were performed in the case record, the discussants order the putative diagnostic test. The result is disclosed along with the pathological discussion and “take home messages” on important differentials in the third part of the session. CC chief complaint, HPI history of present illness, PMH past medical history, Meds medications, SH social history, FH family history, ROS review of systems, VS vital signs, PE physical examination, CMP comprehensive metabolic panel, CBC complete blood count, PT prothrombin time, PTT partial thromboplastin time, UA urine analysis, ECG electrocardiogram, CXR chest radiograph.

Figure 2: Study design. Full data sets of 90 medical students were analysed. T_0: knowledge application pre-test, T_1: knowledge application post-test, T_2: delayed knowledge application post-test.

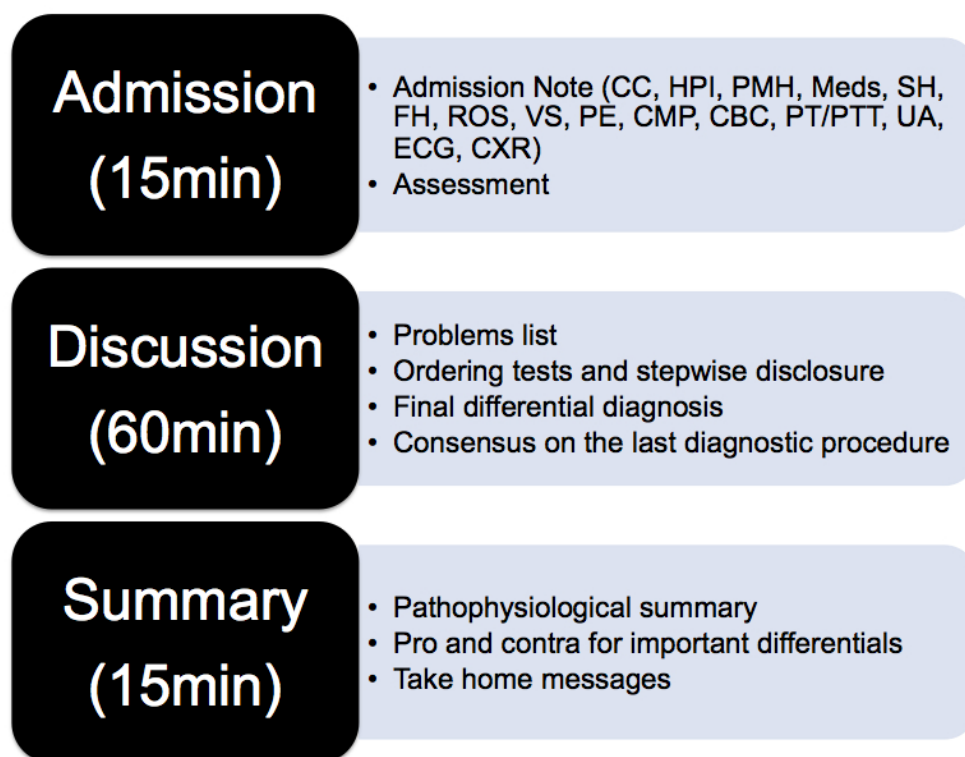


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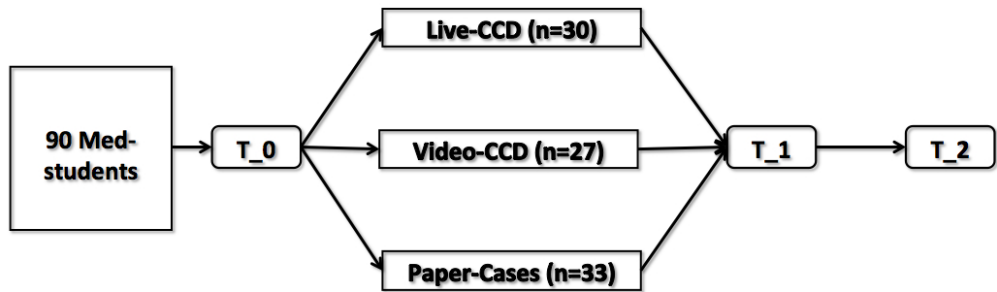


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CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	1
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	2-3
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	4-6
	2b	Specific objectives or hypotheses	6
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	7-9
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	not applicable
Participants	4a	Eligibility criteria for participants	7
	4b	Settings and locations where the data were collected	7
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	7-9
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	9-10
	6b	Any changes to trial outcomes after the trial commenced, with reasons	not applicable
Sample size	7a	How sample size was determined	10
	7b	When applicable, explanation of any interim analyses and stopping guidelines	not applicable
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	7
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	7
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	not applicable
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	not applicable
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those	not applicable

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2		assessing outcomes) and how	
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4		11b If relevant, description of the similarity of interventions	not applicable
5	Statistical methods	12a Statistical methods used to compare groups for primary and secondary outcomes	10
6		12b Methods for additional analyses, such as subgroup analyses and adjusted analyses	10
7			
8	Results		
9	Participant flow (a	13a For each group, the numbers of participants who were randomly assigned, received intended treatment, and	attached as
10	diagram is strongly	were analysed for the primary outcome	supplemental
11	recommended)	13b For each group, losses and exclusions after randomisation, together with reasons	7
12	Recruitment	14a Dates defining the periods of recruitment and follow-up	not applicable
13		14b Why the trial ended or was stopped	not applicable
14	Baseline data	15 A table showing baseline demographic and clinical characteristics for each group	attached as
15			supplemental
16			
17	Numbers analysed	16 For each group, number of participants (denominator) included in each analysis and whether the analysis was	11-12
18		by original assigned groups	
19	Outcomes and	17a For each primary and secondary outcome, results for each group, and the estimated effect size and its	10-13
20	estimation	precision (such as 95% confidence interval)	
21		17b For binary outcomes, presentation of both absolute and relative effect sizes is recommended	not applicable
22	Ancillary analyses	18 Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing	not applicable
23		pre-specified from exploratory	
24	Harms	19 All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	not applicable
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27	Discussion		
28	Limitations	20 Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	15
29	Generalisability	21 Generalisability (external validity, applicability) of the trial findings	14-15
30	Interpretation	22 Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	13-15
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32	Other information		
33	Registration	23 Registration number and name of trial registry	not applicable
34	Protocol	24 Where the full trial protocol can be accessed, if available	17
35	Funding	25 Sources of funding and other support (such as supply of drugs), role of funders	16
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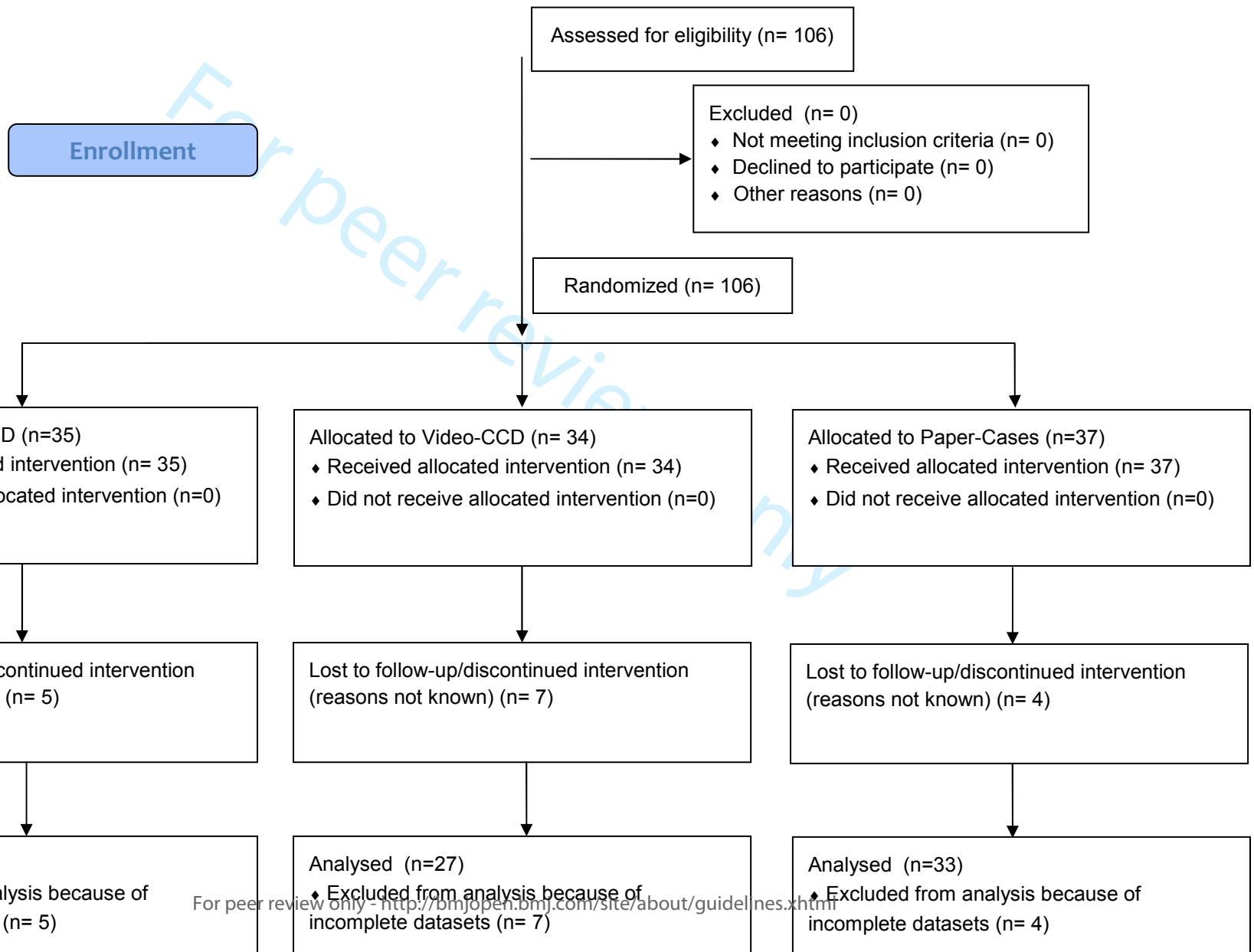
*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up to date references relevant to this checklist, see www.consort-statement.org.



CONSORT

TRANSPARENT REPORTING of TRIALS

CONSORT 2010 Flow Diagram



BMJ Open

Can Clinical Case Discussions foster clinical reasoning skills in undergraduate medical education? A randomised controlled trial

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Primary Subject Heading:	Medical education and training
Secondary Subject Heading:	Medical education and training
Keywords:	Undergraduate medical education, Case-based learning, Clinical reasoning, Social interaction, Medical decision making

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RESEARCH PAPER

**Can Clinical Case Discussions foster clinical reasoning skills in
undergraduate medical education? A randomised controlled trial**

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social interaction, medical decision making

Abstract

Objective: Fostering clinical reasoning is a mainstay of medical education. Based on the Clinicopathological Conferences, we propose a case-based peer teaching approach called Clinical Case Discussions (CCDs) to promote the respective skills in medical students. This study compares the effectiveness of different CCD formats with varying degrees of social interaction in fostering clinical reasoning.

Design, Setting, Participants: A single-center randomised controlled trial with a parallel design was conducted at a German university. The 106 study participants were stratified (age, gender, year of study, prior CCD participation, performance in a pre-test) and tested regarding their clinical reasoning skills right after CCD participation and two weeks later.

Intervention: Participants worked either within a live discussion group (Live-CCD), a group watching recordings of the live discussions (Video-CCD), or a group working with printed cases (Paper-Cases). The presentation of case information followed an admission-, discussion-, summary-sequence.

Primary and secondary outcome measures: Clinical reasoning skills were measured with a knowledge application test addressing the students' conceptual, strategic, and conditional knowledge. Additionally, subjective learning outcomes were assessed.

Results: With respect to learning outcomes, the Live-CCD group displayed the best results, followed by Video-CCD and Paper-Cases. No difference was found between Live-CCD and Video-CCD groups in the delayed post-test; both outperformed the Paper-Cases group. Regarding subjective learning outcomes, the Live-CCD received significantly better ratings than the other formats.

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4 **Conclusions:** This study demonstrates that the CCD approach is an effective and
5 sustainable clinical reasoning teaching resource for medical students. Subjective
6 learning outcomes underline the importance of learner (inter-)activity in the acquisition
7 of clinical reasoning skills in the context of case-based learning. Higher efficacy of
8 more interactive formats can be attributed to positive effects of collaborative learning.
9 Future research should investigate how the Live-CCD format can further be improved
10 and how video-based CCDs can be enhanced through instructional support.
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23 **Article summary**

24 **Strengths and limitations of this study:**

- 25 • First empirical study on the implementation of Clinical Case Discussions in
26 undergraduate medical education.
- 27 • Comparison of Clinical Case Discussions with differing grades of social
28 interaction to determine their effectiveness on medical students' acquisition of
29 clinical reasoning skills by between-group analyses.
- 30 • Implementation of multidimensional and multilayered test instruments in a pre-,
31 post- and delayed post-test design to measure clinical reasoning skills by a
32 knowledge application test and self-assessment.
- 33 • The knowledge application test utilized in this study did not allow for a more in-
34 depth analysis of clinical reasoning skills (i.e. a distinction of conceptual,
35 strategic, and conditional knowledge).
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Introduction

Curriculum developers face the challenge of implementing competence-oriented frameworks such as CanMEDS (Canada), the NKLM (Germany) or PROFILES (Switzerland), including the need to train clinical reasoning skills as a medical doctor's key competence.[1-3] As such, clinical reasoning skills are crucial not only for appropriate medical decision making, but also to avoid diagnostic errors and the associated harm for both patients and healthcare systems.[4]

Case-based learning has been proposed to foster clinical reasoning skills[5] and is well accepted amongst students.[6] Case-based learning found an early representation in Clinicopathological Conferences (CPC, first introduced by Cannon in 1900[7]) which are practiced until today. The Clinicopathological Conferences conducted at the Massachusetts General Hospital are published on a regular basis known as the *Case Records* series of the New England Journal of Medicine. In those CPCs the “medical mystery”[8] presented by the case under discussion calls readers to think about the possible diagnosis themselves, before it is finally disclosed at the last part of the CPC. Despite the absence of definitive evidence for efficacy as a teaching method, CPCs have widely been used in medical education since the early 20th century to foster clinical reasoning.[9-11] While these CPC-Case Records reaches lots of medical readers around the world, it has been criticised as being anachronistic with a diagnosing “star (i.e. the discussant), performing, acutely aware of being the center of attention”.[12]

Case-based learning formats are embedded in a context, which is known to promote learning better than providing facts in an abstract, non-contextual form.[13] A definition found in the review by Merseth suggests three essential elements of a case: A case is real (i.e. based on a real-life situation or event); it relies on careful research and study; it

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4 is “created explicitly for discussion and seeks to include sufficient detail and
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6 information to elicit active analysis and interpretation by users”.[14] Cases may be
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8 represented by means of text, pictures, videos, and the like. Realism and authenticity are
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10 varying features of cases,[15] but particularly elaborated and authentic cases provide
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12 increased diagnostic challenge, comprising an additional value for medical training.[16]
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14 However, due to their setup, CPCs are often a passive learning situation for participants,
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16 as they listen to the discussant laying out his or her clinical reasoning on the case under
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18 discussion. According to the ICAP framework by Chi et al.,[17] teaching formats
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20 increase their efficacy from passive < active < constructive < interactive learning
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22 environments. Based on the ICAP model, any intervention that would lead to more
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24 effective cognitive (i.e. constructive or interactive) learner activities should improve the
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26 learning outcomes of that format. Especially when students interactively engage in
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28 discussions among each other, learning is enhanced. Accordingly, case-based learning
29
30 has been found to be particularly beneficial in collaborative settings.[15] However,
31
32 another important aspect to consider in collaborative learning environments is that some
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34 students may participate passively while others contribute disproportionately much. To
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36 foster optimal learning effects, students should thus be encouraged to be interactively
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38 engaged. One prerequisite to achieve self-guided learning in groups is a low threshold
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40 for students to come forward with their questions and participate in ensuing
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42 discussions.[18] To this end, peer teaching has been established as an effective tool to
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44 stimulate discussions.[19] To make sure peer tutors are not overwhelmed in moderating
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46 these discussions, the presence of an experienced clinician appears to be warranted[20]
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48 in addition to a specific training of the tutors.
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4 Taken together, while traditional CPCs encompass some important dimensions of
5 effective case-based learning environments, they are not systematically aiming at
6 constructive or interactive learner activities that are known features of effective teaching
7 formats.[17,21] Therefore, we introduced Clinical Case Discussions (CCD) in
8 undergraduate medical education to account for these features. We still use the Case
9 Records of the Massachusetts General Hospital,[9] as these cases exemplify realistic
10 patient encounters and fulfill the criteria for an interactive collaborative learning process
11 as explained above. In the CCD approach, cases are presented only until the hospital
12 admission of the patient, followed by an interactive discussion about possible diagnoses
13 and diagnostic strategies. After all test results have been discussed, the actual diagnosis
14 is disclosed and the pitfalls and take-home messages of the case are summarised.

15
16 To investigate the effectiveness of the CCD approach in undergraduate medical
17 education, we designed an intervention trial and assessed clinical reasoning skills in
18 medical students before and after *participating in live CCDs* or *being exposed* to video
19 recordings of live CCDs. We compared these formats and its effects on clinical
20 reasoning with the more traditional approach of working through written cases. When
21 carrying out this randomised trial, we hypothesised that participation in live CCD
22 sessions would lead to a higher increase of clinical reasoning skills than simply reading
23 the cases. To better understand possible effects of the CCD learning environment with
24 its social components on learning outcomes, participation in live CCDs as outlined
25 above was additionally compared to the effects of watching videos of CCDs online.
26 This comparison also seemed relevant from an economic point of view as video-
27 streaming of lectures and seminars are prevalent at many institutions in higher
28 education allowing for flexible and scalable access to learning materials.[22] To
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investigate the potential of different CCD formats for regular curricular use, we also measured subjective learning outcomes after the intervention and correlated student self-assessments with objective changes in their clinical reasoning skills.

Methods

Participants / Ethics

Initially, we recruited 106 volunteer medical students at the Medical Faculty of LMU Munich. Randomisation was performed in a two-step procedure: First, we selected a sample of roughly 100 enrolled students. Next, we stratified participants by creating triplets on the basis of the variables age, gender, year of study, prior CCD participation and performance in a knowledge application pre-test. This was done in an effort to limit the risk of random misdistribution of the selected sample. From each triplet we randomly assigned participants to the experimental groups. A total of 90 participants eventually completed the study, 31 of them were male and 59 female. They were 20 to 41 years old ($M = 23$; $SD = 2.97$) and in their first to eighth clinical semester ($M = 3.5$; $SD = 1.78$).

The study was approved by the ethics committee of the Medical Faculty of LMU Munich (approval reference no. 222-15). Written informed consent was obtained from all study participants and they received a financial reimbursement of 50 Euros upon completion of the trial.

Patient and public involvement

No patients or public were involved in this research.

Study design

We conducted a single-center randomised controlled trial consisting of a total of five course sessions with a parallel design (see Figure 1). One week prior to the first CCD session, participants were introduced to the principles of the CCD approach and the sequence of this trial in an introductory session where they also took a knowledge application pre-test (T_0). In the experimental phase, participants attended three weekly interventional course sessions of 90 minutes each in one of the three aforementioned groups with the respective CCD formats. Participants took a knowledge application post-test at the end of the last experimental course session (T_1), four weeks after pre-testing. A delayed knowledge application post-test was conducted two weeks after completion of the interventional courses (T_2); we deliberately chose that time interval to investigate the sustainability of possibly effects while balancing the risk of post-intervention confounding.[23]

Insert Figure 1 about here

Materials

In all experimental groups the intervention was based on the same three, independent internal medicine cases. Chief complaints in these cases were paresthesia (first session), fever and respiratory failure (second session), and rapidly progressive respiratory failure (third session).[24-26] Cases were worked through in an iterative approach in different formats: (a) peer-moderated live case discussions in an interactive setting (Live-CCD, $n = 30$), (b) a single-learner format utilizing an interactive multimedia platform displaying video recordings of the live case discussions (Video-CCD, $n = 27$), and (c) a single-learner format in which the students worked with the original paper cases of the NEJM

(Paper-Cases, $n = 33$). The cases were prepared in a way that participants in each format were exposed to the same case information.

Procedure

In all three groups cases were presented in a specified structured manner similar to the original Clinicopathological Conferences (see Figure 2). In each format the students (“discussants”) had to fill out a form after the admission in which the case had to be summarised and a list of clinical problems and working diagnoses had to be provided. Subsequently, between discussion and summary a second case-summary had to be completed in which the final diagnostic test and the most likely diagnosis had to be proposed.

Insert Figure 2 about here

In the Live-CCD group, the case presentation was prepared beforehand by a voluntary discussant (“presenter”), who presented the facts in the admission (according to the structure shown in Figure 2). Electronic slides and flipcharts were used to transport case information. Original test results were revealed by the presenter during the discussion only when requested by the group of students. Furthermore, the presenter summarised the differential diagnosis, important pathophysiological features of the case at the end of the session and provided a short take home message. The moderating medical students (“moderator”) were recruited among previous CCD participants. They had experience in CCD moderation and had had an introductory training (two days) in higher education methods and group facilitation prior to the study. The moderator facilitated the discussion process and ensured a reasonable approach to the patient encounter (e.g. with

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4 respect to timing and hierarchy of ordered tests) in close communication with the
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6 discussants. Moreover, the moderator helped students develop their diagnostic strategy
7
8 by co-evaluating their requested findings and the reasoning employed. Supervision of
9
10 the correctness of medical facts and the correct diagnostic approach were ultimately
11
12 granted by a clinician who could stop the discussion at any point when faulty reasoning
13
14 was evident or discussants explicitly requested the facilitation of an experienced
15
16 physician. The clinicians' level of involvement into the discussion was left at their own
17
18 discretion. We varied the staff between each Live-CCD to minimise effects of personal
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20 teacher characteristics. Live sessions typically lasted 90 minutes and were recorded with
21
22 multiple cameras.
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27 Students in the Video-CCD format worked on a single-learner multimedia workstation
28
29 on which a video recording of the Live-CCD were displayed. These recordings also
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31 contained the electronic slide presentation from the Live-CCD and enabled
32
33 simultaneous observation of the discussion from multiple camera angles. Participants
34
35 could pause and partially skip the videos.
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39 In the Paper-Cases group participants received the case information of each CCD
40
41 section sequentially (i.e. admission, discussion, summary) in a print format. In both
42
43 single-learner formats students could choose their personal working speed. There was
44
45 neither a prespecified minimum nor a maximum time they were required to work on the
46
47 cases. In each of the three formats full access to the internet was permitted for additional
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49 information.
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Instruments

Learning outcomes with respect to clinical reasoning were measured with a knowledge application test that consisted of 29 items (i.e. a maximum of 29 points could be achieved) and was to be filled out within 45 minutes. The knowledge application test was based on instruments previously developed at the Institute for Medical Education at LMU Munich.[27-29] It comprised multiple choice items, key feature problems and problem-solving tasks, addressing the conceptual, strategic, and conditional knowledge of the participants (see Figure 3). Meta-analyses on retest effects suggest that score increase is higher for identical forms than for parallel test forms.[30] In order to limit such effects, we applied parallel forms of the knowledge application test for pre- and post-measurements (i.e. topics covered by the individual items were the same, but the items were reformulated and their order was permuted). Overall test difficulty was chosen to be high in order to avoid ceiling effects, as students from all clinical years were allowed to participate in the study. Overall test reliability was satisfactory (Cronbach's $\alpha = .71$).

Insert Figure 3 about here

Subjective learning outcomes were measured at T₁ with a short questionnaire consisting of 9 items (e.g. "I learned a lot during the CCD course", "The CCD course increased my learning motivation" or "I recommend the implementation of the CCD teaching format into the curriculum"; the full questionnaire is available as a supplementary file). Participants were asked to rate these items on a Likert scale ranging from 1 (I don't agree) to 5 (I fully agree). Reliability of the corresponding scale was good (Cronbach's $\alpha = .95$). Additionally, study participants were asked to share their

views on positive and negative aspects of the respective training format through open items at the end of the questionnaire.

Statistical Analysis

The required sample size ($N = 128$) was estimated to detect medium effect sizes with a power of 80% and a significance level of $\alpha = .05$. For between-group analyses, one-way ANOVAs were conducted with *post-hoc* Bonferroni tests for multiple comparisons.

Results

Effects of the CCD format on learning outcomes related to Clinical Reasoning

Experimental groups differed significantly with respect to the knowledge application post-test (see Table 1), $F(2,87) = 27.07, p = .000$, partial $\eta^2 = .384$ (this corresponds to a Cohen's d of 1.580). The Live-CCD group ($M = 14.10; SD = 3.32$) outperformed both the Video-CCD ($M = 11.69; SD = 3.34$) and the Paper-Cases group ($M = 8.5; SD = 2.44$). Post hoc Bonferroni tests revealed significant differences between Live-CCD and Video-CCD ($p = .011$) as well as the Paper-Cases group ($p = .000$). The difference in the knowledge application post-test between Video-CCD and the Paper-Cases group was also significant ($p = .000$).

Two weeks after course completion, the effect of the teaching format was still found in a delayed knowledge application post-test, $F(2,87) = 30.91, p = .000$, partial $\eta^2 = .415$ (this corresponds to a Cohen's d of 1.685). Both Live-CCD ($M = 13.36; SD = 3.23$) and the Video-CCD ($M = 11.84; SD = 2.92$) outperformed the Paper-Cases group ($M = 7.89; SD = 2.41$). Post hoc Bonferroni tests revealed significant differences between the Live-CCD and Paper-Cases group ($p = .000$) as well as between the Video-CCD and Paper-

Cases group ($p = .000$). However, the difference between Live-CCD and Video-CCD was not significant in the delayed knowledge application post-test ($p = .146$).

Table 1. Overview of the findings of the study.

	Teaching format					
	Live-CCD		Video-CCD		Paper-Cases	
	M	(SD)	M	(SD)	M	(SD)
Knowledge application pre-test	5.34	(1.92)	4.76	(1.90)	5.76	(2.24)
	$n = 30$		$n = 27$		$n = 33$	
Knowledge application post-test	14.10	(3.32)	11.69	(3.34)	8.50	(2.44)
	$n = 30$		$n = 27$		$n = 33$	
Delayed knowledge application post-test	13.36	(3.23)	11.84	(2.92)	7.89	(2.41)
	$n = 30$		$n = 27$		$n = 33$	
Subjective learning outcomes	4.20	(.63)	3.18	(1.24)	3.00	(.99)
	$n = 30$		$n = 27$		$n = 31$	

Effects of the CCD format on subjective learning outcomes

Experimental groups differed significantly with respect to subjective learning outcomes (see Table 1), $F(2,85) = 13.16$, $p = .000$, partial $\eta^2 = .236$ (this corresponds to a Cohen's d of 1.112). Participants of the Live-CCD group ($M = 4.20$; $SD = .63$) assigned better ratings to their course format than participants in the Video-CCD group ($M = 3.18$; $SD = 1.24$) and the Paper-Cases group ($M = 3.0$; $SD = .99$). Post hoc Bonferroni tests showed that the Live-CCD differed from the Video-CCD ($p = .001$) and the Paper-Cases group ($p = .000$) in this regard. An additional Duncan post-hoc test confirmed that the Video-CCD and the Paper-Cases group did not differ from each other in this regard ($p = .48$).

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4 To investigate the relations between the subjective assessment and the knowledge
5 application tests applied at the end and two weeks after the course, we calculated
6 correlations between the different outcome measures. Subjective learning outcomes
7 correlated on a medium level with both the knowledge application post-test ($r = .343$, n
8 = 88, $p = .001$) and the delayed knowledge application post-test ($r = .339$, $n = 88$, $p =$
9 .001).
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18 In the Live-CCD group, 83% of the students were in favour of implementing routine
19 Live-CCD into the medical curriculum. Only 45% and 31% of students from the Video-
20 CCD and Paper-Cases groups voted for an implementation of their respective course in
21 the curriculum. With respect to the open items from the subjective learning outcomes
22 questionnaire, participants from all groups praised the quality of the cases. Participants
23 from the Live-CCD group particularly valued their course format for providing an
24 opportunity to practice “diagnostic thinking” and the “focus on practice elements”. They
25 also mentioned that “you can look up theoretical knowledge, but you can’t look up
26 applied knowledge”. Students in the Video-CCD group, on the other hand, praised
27 features of the digital learning environment as they could “pause, reflect, or quickly do a
28 Google search” when watching the case discussions. However, they also criticised it
29 was not possible for them to “participate in a more active way”.
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48 **Discussion**

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51 This randomised controlled study shows that even relatively short CCD interventions
52 can lead to improved and sustainable learning outcomes with respect to clinical
53 reasoning. This provides evidence that the CCD approach, which is based on
54 Clinicopathological Conferences, is an effective teaching resource to foster clinical
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4 reasoning skills in medical students. We had hypothesised that a more interactive course
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6 format would result in an improvement of clinical reasoning skills when compared with
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8 less interactive formats. Results show that the Live-CCD indeed leads to the highest
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10 learning outcomes in medical students compared to less interactive formats. Consistent
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12 with our hypothesis, clinical reasoning skills, as measured with our knowledge
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14 application test, had the highest gain in the Live-CCD group. These positive effects of
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16 the CCD teaching format on clinical reasoning skills proved sustainable as shown by the
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18 results in the delayed knowledge application post-test. Overall, these results are in line
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20 with a recently published study on diagnostic reasoning[31] where students who worked
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22 in pairs were more accurate in their diagnosis than individual students despite having
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24 comparable knowledge. Collaborative clinical reasoning has thus far been
25
26 underrepresented in the literature, yet seems to solve many of the educational problems
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28 regarding diagnostic errors.[32]

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34 The significant difference between the Live-CCD and the Video-CCD group can be
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36 explained by the findings of a meta-analysis that showed technology-assisted single-
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38 person learning to be inferior to group learning because of the decreased social
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40 interaction.[33] However, it is important to note that two weeks after the course,
41
42 participants of the Live-CCD and Video-CCD groups did not differ significantly
43
44 anymore while both groups still clearly outperformed the Paper-Case group. In other
45
46 words, watching a video of the live case discussion was found to be more beneficial for
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48 learners regarding their clinical reasoning skills than just reading the printed cases. We
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50 cannot rule out that Live-CCD and Video-CCD groups did not differ in the delayed
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52 knowledge application post-test due to underpowering of the study. As our trial was not
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54 designed to detect smaller effect sizes, this finding has to be treated with caution.
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4 Subjective learning outcomes suggest that students prefer the live discussion over the
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6 other formats and were linked to their performance in the knowledge application test.
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8 Additional qualitative data from the open item answers suggests that the Live-CCD
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10 format supported students in performing clinical reasoning and that the active
11
12 discussion of cases was particularly valued by the students.
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18 **Generalisability**

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20 The conclusions of this study are applicable to a broader audience of medical students.
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22 The CCD approach and its respective formats can easily be implemented in routine
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24 medical education. Peer teaching courses hold the promise of being more easy to install
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26 and more easy to staff than courses led by faculty. Of course, live CCDs still come with
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28 certain personnel requirements, as faculty as well as a moderator need to be present.
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30 Special preparation is not necessary for the clinician though, so total time requirements
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32 might still be lower compared to other teaching formats. Likewise, the implementation
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34 of a singular two-day training for moderators should not require extensive resources.
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36 The study population consisting of students with heterogeneous levels of clinical
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38 experience implies that the CCD is an effective teaching format not only for students at
39
40 the beginning of their clinical career but also for intermediate students. On the other
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42 hand, generalisability is potentially limited as only students from one medical school
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44 participated in our study.
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52 **Limitations of the study**

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54 There are certain limitations of this study that have to be addressed: One important
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56 limitation is the single-centre nature of this study and the relatively small sample size.
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4 Before the CCD approach can be implemented on a larger scale, a validation of our
5 findings is therefore required. Caution is clearly warranted with the effect sizes shown
6 in this trial, as it has been shown that effect sizes of learning intervention trials tend to
7 be inflated compared to the effectiveness of the intervention when used in routine
8 education.[34] Since we did not limit the time students had to work on the cases, we
9 cannot entirely rule out that less time was spent on task in the single-learner formats and
10 particularly the Paper-Cases group. Against this backdrop, we suggest replication to
11 further validate the results found in this study and strengthen the outlined implications.
12 Finally, the knowledge application test utilized in this study did not allow for a more in-
13 depth analysis of clinical reasoning skills (i.e. a distinction of conceptual, strategic, and
14 conditional knowledge). Larger item numbers could facilitate a reliable assessment of
15 changes on the level of corresponding subscales.
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34 **Implications for policy makers / Future research questions**

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36 Based on our findings, the CCD approach is a useful asset for medical educators to
37 widen the range of clinical reasoning teaching tools. Live-CCD can thus be seen as a
38 prime candidate for routine implementation in clinical reasoning curricula. Future
39 research should aim to identify which Live-CCD elements (the roles, case contents, or
40 the course structure) contribute in which way to the improvement of clinical reasoning
41 skills in medical students. The question if and to what extent such skills are applicable
42 across domains is currently being discussed.[35] Future studies may also address the
43 issue of transfer (i.e. to what extent can clinical reasoning skills obtained in case-based
44 training later be applied to different cases?).[36] Regarding the Video-CCD, means of
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4 instructional support to increase the effectiveness and interactivity of the video-based
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6 format should be investigated in an attempt to exploit its full potential.
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15
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43
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49 **Competing Interests**

50
51 Marc Weidenbusch declares to have no conflict of interest.

52
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6 Jan Kiesewetter declares to have no conflict of interest.

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8
9 Martin R. Fischer declares to have no conflict of interest.

10
11 Jan M. Zottmann declares to have no conflict of interest.

12 13 14 15 16 **Author contributions**

17
18 MW, BL, MF and JZ planned the study.

19
20 MW, BL and CS were responsible for data acquisition.

21
22 MW, BL, RK, JK, JZ and MS analysed and interpreted the data.

23
24
25 MW, BL and JZ drafted and revised the manuscript, all authors contributed significant
26
27 intellectual content and all authors gave final approval of the version to be published.
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30 31 32 **Data sharing statement**

33
34 Dataset and detailed information about the CCD formats is available upon request.
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39 40 **References**

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Figure legends

Figure 1: Study design. Full data sets of 90 medical students were analysed. T_0: knowledge application pre-test, T_1: knowledge application post-test, T_2: delayed knowledge application post-test.

Figure 2: Live-CCD Structure. CCD sessions are divided into three parts: In the *admission* part the presenting student shows the discussants his prepared slides (based on the original NEJM-case record), after which the group has to agree on an assessment of the patient under discussion. In the interactive *discussion* part the students prioritise the medical problems, link them to possible etiologies and order tests to further corroborate or discard differential diagnoses. After all the tests that were performed in the case record, the discussants order the putative diagnostic test. The result is disclosed along with the pathological discussion and “take home messages” on important differentials in the third part of the session. CC chief complaint, HPI history of present illness, PMH past medical history, Meds medications, SH social history, FH family history, ROS review of systems, VS vital signs, PE physical examination, CMP comprehensive metabolic panel, CBC complete blood count, PT prothrombin time, PTT partial thromboplastin time, UA urine analysis, ECG electrocardiogram, CXR chest radiograph.

Figure 3: Knowledge application test. Exemplary items are shown for each of the knowledge types addressed (arrows point to the correct answers). The test included 11 items on conceptual knowledge, 9 items on strategic knowledge, and 9 items on conditional knowledge.

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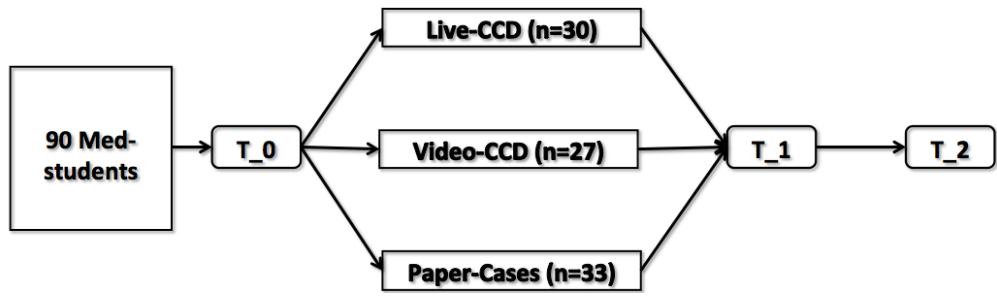


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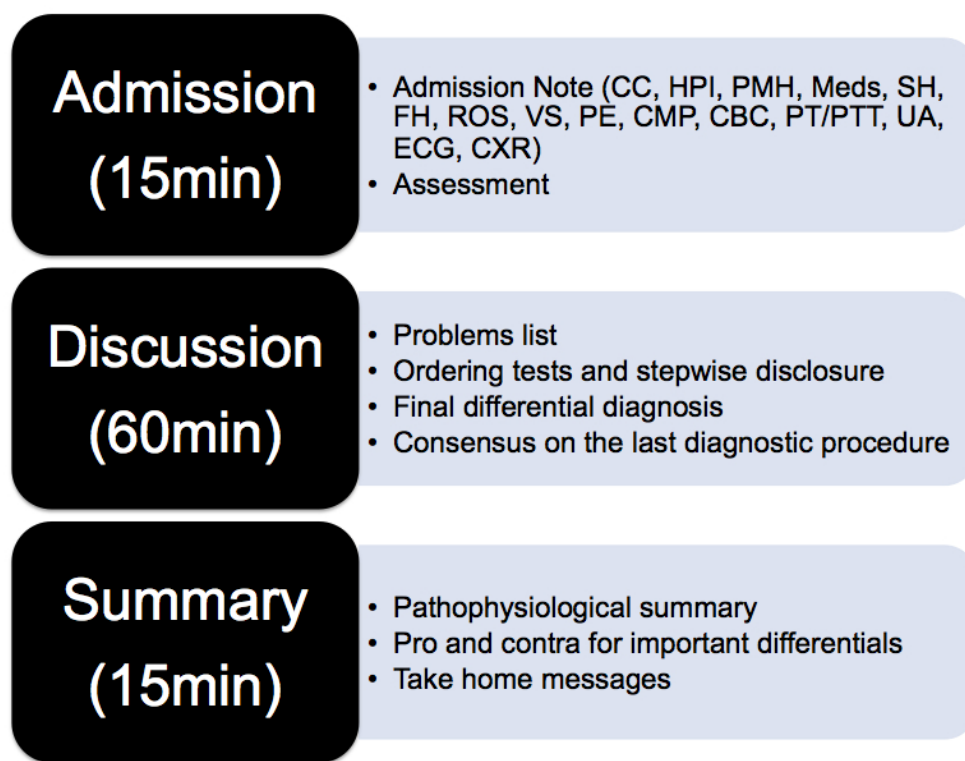


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Conceptual knowledge

- What of the following medications is a neuraminidase inhibitor?
Amantadin / Ledipasvir / Tenofovir / Dolutegravir / ➡ **Zanamivir**

Strategic knowledge

A 54 year old woman is brought into your emergency department by EMS with cough, fever and dyspnea. History taking is almost impossible because the patient is somnolent. Her vital signs are: T 39,2 °C, BP 120/80 mmHG, HF 90 bpm, AF 30/min, SpO₂ 83% on ambient air, raising to 87% with 15l O₂/min on a non-rebreather mask. PE: diffuse crackles over both lungs, peripheral cyanosis.

- What is the most pressing diagnostic or therapeutic measure?
➡ **Intubation**

Conditional knowledge

A 42 year old women presents with a body weight of 35 kg and a BMI of 19,2. The patient tells you while weight loss was intentional in the beginning, it has now by far exceeded the desired extent. Lab values show macrocytic anemia and thrombocytopenia along with an eosinophilia of 800/μl. You suspect an infection with the fish tape worm *Diphyllobothrium latum*.

- Please elaborate what processes might underly the weight loss and the bicytopenia.
➡ **Tape worm infection causes vitamin B12 deficiency-induced bicytopenia and malnutrition because of biological competition for enteral resorption of vitamins and nutrients**

Figure 3: Knowledge application test. Exemplary items are shown for each of the knowledge types addressed (arrows point to the correct answers). The test included 11 items on conceptual knowledge, 9 items on strategic knowledge, and 9 items on conditional knowledge.

154x138mm (600 x 600 DPI)

Supplemental

Baseline data: Demographic characteristics of the study participants.

	CCD format							
	Live-CCD		Video-CCD		Paper-Cases		All formats	
	<i>n</i> = 30		<i>n</i> = 27		<i>n</i> = 33		<i>N</i> = 90	
Gender distribution	14/16		5/22		12/21		31/59	
<i>N</i> m/f								
(% f)	(53.3% f)		(81.5% f)		(63.6% f)		(65.6% f)	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)
Age	23.77	(4.09)	22.26	(1.77)	22.91	(2.40)	23.0	(2.97)
Clinical semester	3.23	(1.96)	3.41	(1.47)	3.82	(1.84)	3.50	(1.78)
High school grade	1.53	(0.36)	1.35	(0.42)	1.48	(0.68)	1.46	(0.52)
First National Board Exam	245		226		246		240	
Score	(30)		(78)		(30)		(49)	
Participants with prior	6		6		5		17	
CCD experience	(20.0%)		(22.2%)		(15.1%)		(18.9%)	
n (%)								

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3 *Questionnaire items (5-point Likert scale) for the assessment of subjective learning outcomes.*
4
5

- 6 1. I perceived this CCD format as meaningful.
 - 7 2. I learned a lot during the CCD course.
 - 8 3. The CCD course increased my learning motivation.
 - 9 4. I would like to participate in this CCD format again in the future.
 - 10 5. I enjoyed the CCD course.
 - 11 6. This CCD format should be offered as part of the curriculum.
 - 12 7. I was able to follow the case discussions.
 - 13 8. Learning in the CCD format is easier for me than learning in traditional lectures or seminars.
 - 14 9. How would you rate the course overall?
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CONSORT 2010 Flow Diagram

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Enrollment

Assessed for eligibility (n=106)

Excluded (n=0)
 ♦ Not meeting inclusion criteria (n=0)
 ♦ Declined to participate (n=0)
 ♦ Other reasons (n=0)

Randomised (n=106)

Allocation

Allocated to Live-CCD (n=35)
 ♦ Received allocated intervention (n=35)
 ♦ Did not receive allocated intervention (n=0)

Allocated to Video-CCD (n=34)
 ♦ Received allocated intervention (n=34)
 ♦ Did not receive allocated intervention (n=0)

Allocated to Paper-Cases (n=37)
 ♦ Received allocated intervention (n=37)
 ♦ Did not receive allocated intervention (n=0)

Follow-Up

Lost to follow-up/discontinued intervention (reasons not known) (n=5)

Lost to follow-up/discontinued intervention (reasons not known) (n=7)

Lost to follow-up/discontinued intervention (reasons not known) (n=4)

Analysis

Analysed (n=30)
 ♦ Excluded from analysis because of incomplete datasets (n=5)

Analysed (n=27)
 ♦ Excluded from analysis because of incomplete datasets (n=7)

Analysed (n=33)
 ♦ Excluded from analysis because of incomplete datasets (n=4)



CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	1
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	2-3
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	4-7
	2b	Specific objectives or hypotheses	6-7
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	8
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	not applicable
Participants	4a	Eligibility criteria for participants	7
	4b	Settings and locations where the data were collected	7
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	8-10
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	8, 11-12
	6b	Any changes to trial outcomes after the trial commenced, with reasons	not applicable
Sample size	7a	How sample size was determined	12
	7b	When applicable, explanation of any interim analyses and stopping guidelines	not applicable
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	7
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	7
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	not applicable
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	not applicable
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those	not applicable

		assessing outcomes) and how	
	11b	If relevant, description of the similarity of interventions	not applicable
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	12
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	12
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	attached as supplemental
	13b	For each group, losses and exclusions after randomisation, together with reasons	7
Recruitment	14a	Dates defining the periods of recruitment and follow-up	not applicable
	14b	Why the trial ended or was stopped	not applicable
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	attached as supplemental
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	13
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	12-14
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	not applicable
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	not applicable
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	not applicable
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	16-17
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	16
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	14-16
Other information			
Registration	23	Registration number and name of trial registry	not applicable
Protocol	24	Where the full trial protocol can be accessed, if available	19
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	18

*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up to date references relevant to this checklist, see www.consort-statement.org.

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Can Clinical Case Discussions foster clinical reasoning skills in undergraduate medical education? A randomised controlled trial

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Primary Subject Heading:	Medical education and training
Secondary Subject Heading:	Medical education and training
Keywords:	Undergraduate medical education, Case-based learning, Clinical reasoning, Social interaction, Medical decision making

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RESEARCH PAPER

**Can Clinical Case Discussions foster clinical reasoning skills in
undergraduate medical education? A randomised controlled trial**

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Keywords: undergraduate medical education, case-based learning, clinical reasoning,
social interaction, medical decision making

Abstract

Objective: Fostering clinical reasoning is a mainstay of medical education. Based on the Clinicopathological Conferences, we propose a case-based peer teaching approach called Clinical Case Discussions (CCDs) to promote the respective skills in medical students. This study compares the effectiveness of different CCD formats with varying degrees of social interaction in fostering clinical reasoning.

Design, Setting, Participants: A single-center randomised controlled trial with a parallel design was conducted at a German university. The 106 study participants were stratified (age, gender, year of study, prior CCD participation, performance in a pre-test) and tested regarding their clinical reasoning skills right after CCD participation and two weeks later.

Intervention: Participants worked either within a live discussion group (Live-CCD), a group watching recordings of the live discussions (Video-CCD), or a group working with printed cases (Paper-Cases). The presentation of case information followed an admission-, discussion-, summary-sequence.

Primary and secondary outcome measures: Clinical reasoning skills were measured with a knowledge application test addressing the students' conceptual, strategic, and conditional knowledge. Additionally, subjective learning outcomes were assessed.

Results: With respect to learning outcomes, the Live-CCD group displayed the best results, followed by Video-CCD and Paper-Cases. No difference was found between Live-CCD and Video-CCD groups in the delayed post-test; both outperformed the Paper-Cases group. Regarding subjective learning outcomes, the Live-CCD received significantly better ratings than the other formats.

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4 **Conclusions:** This study demonstrates that the CCD approach is an effective and
5 sustainable clinical reasoning teaching resource for medical students. Subjective
6 learning outcomes underline the importance of learner (inter-)activity in the acquisition
7 of clinical reasoning skills in the context of case-based learning. Higher efficacy of
8 more interactive formats can be attributed to positive effects of collaborative learning.
9 Future research should investigate how the Live-CCD format can further be improved
10 and how video-based CCDs can be enhanced through instructional support.
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23 **Article summary**

24 **Strengths and limitations of this study:**

- 25 • First empirical study on the implementation of Clinical Case Discussions in
26 undergraduate medical education.
- 27 • Comparison of Clinical Case Discussions with differing grades of social
28 interaction to determine their effectiveness on medical students' acquisition of
29 clinical reasoning skills by between-group analyses.
- 30 • Implementation of multidimensional and multilayered test instruments in a pre-,
31 post- and delayed post-test design to measure clinical reasoning skills by a
32 knowledge application test and self-assessment.
- 33 • The knowledge application test utilized in this study did not allow for a more in-
34 depth analysis of clinical reasoning skills (i.e. a distinction of conceptual,
35 strategic, and conditional knowledge).
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Introduction

Curriculum developers face the challenge of implementing competence-oriented frameworks such as CanMEDS (Canada), the NKLM (Germany) or PROFILES (Switzerland), including the need to train clinical reasoning skills as a medical doctor's key competence.[1-3] As such, clinical reasoning skills are crucial not only for appropriate medical decision making, but also to avoid diagnostic errors and the associated harm for both patients and healthcare systems.[4]

Case-based learning has been proposed to foster clinical reasoning skills[5] and is well accepted among students.[6] Case-based learning found an early representation in Clinicopathological Conferences (CPC, first introduced by Cannon in 1900[7]) which are practiced until today. The Clinicopathological Conferences conducted at the Massachusetts General Hospital are published on a regular basis known as the *Case Records* series of the New England Journal of Medicine. In those CPCs the “medical mystery”[8] presented by the case under discussion calls readers to think about the possible diagnosis themselves, before it is finally disclosed at the last part of the CPC. Despite the absence of definitive evidence for efficacy as a teaching method, CPCs have widely been used in medical education since the early 20th century to foster clinical reasoning.[9-11] While these CPC-Case Records reaches lots of medical readers around the world, it has been criticised as being anachronistic with a diagnosing “star (i.e. the discussant), performing, acutely aware of being the center of attention”.[12]

Case-based learning formats are embedded in a context, which is known to promote learning better than providing facts in an abstract, non-contextual form.[13] A definition found in the review by Merseth suggests three essential elements of a case: A case is real (i.e. based on a real-life situation or event); it relies on careful research and study; it

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4 is “created explicitly for discussion and seeks to include sufficient detail and
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6 information to elicit active analysis and interpretation by users”.^[14] Cases may be
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8 represented by means of text, pictures, videos, and the like. Realism and authenticity are
9
10 varying features of cases,^[15] but particularly elaborated and authentic cases provide
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12 increased diagnostic challenge, comprising an additional value for medical training.^[16]
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14 However, due to their setup, CPCs are often a passive learning situation for participants,
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16 as they listen to the discussant laying out his or her clinical reasoning on the case under
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18 discussion. According to the ICAP framework by Chi et al.,^[17] teaching formats
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20 increase their efficacy from passive < active < constructive < interactive learning
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22 environments. Learning is enhanced when students interactively engage in discussions
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24 among each other. Accordingly, case-based learning has been found to be particularly
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26 beneficial in collaborative settings.^[15] However, another important aspect to consider
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28 in collaborative learning environments is that some students may participate passively
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30 while others contribute disproportionately much. To foster optimal learning effects,
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32 students should thus be encouraged to be interactively engaged. One prerequisite to
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34 achieve self-guided learning in groups is a low threshold for students to come forward
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36 with their questions and participate in ensuing discussions.^[18] To this end, peer
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38 teaching has been established as an effective tool to stimulate discussions.^[19] To make
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40 sure peer tutors are not overwhelmed in moderating these discussions, the presence of
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42 an experienced clinician appears to be warranted^[20] in addition to a specific training of
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44 the tutors.
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52 Taken together, while traditional CPCs encompass some important dimensions of
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54 effective case-based learning environments, they are not systematically aiming at
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56 constructive or interactive learner activities that are known features of effective teaching
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4 formats.[17,21] Therefore, we introduced Clinical Case Discussions (CCD) in
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6 undergraduate medical education to account for these features. We still use the Case
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8 Records of the Massachusetts General Hospital,[9] as these cases exemplify realistic
9
10 patient encounters and fulfill the criteria for an interactive collaborative learning process
11
12 as explained above. In the CCD approach, cases are typically presented with
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14 information until the admission of the patient to the hospital. This event is usually the
15
16 starting point of an interactive discussion phase of the group about possible diagnoses
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18 and diagnostic strategies. After all test results have been discussed, the actual diagnosis
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20 is disclosed and the pitfalls and take-home messages of the case are summarised.
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24 To investigate the effectiveness of the CCD approach in undergraduate medical
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26 education, we designed an intervention trial and assessed clinical reasoning skills in
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28 medical students before and after *participating in live CCDs or being exposed to video*
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30 recordings of live CCDs. We compared these formats and its effects on clinical
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32 reasoning with the more traditional approach of working through written cases. When
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34 carrying out this randomised trial, we hypothesised that participation in live CCD
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36 sessions would lead to a higher increase of clinical reasoning skills than simply reading
37
38 the cases. To better understand possible effects of the CCD learning environment with
39
40 its social components on learning outcomes, participation in live CCDs as outlined
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42 above was additionally compared to the effects of watching videos of CCDs online.
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44 This comparison also seemed relevant from an economic point of view as video-
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46 streaming of lectures and seminars are prevalent at many institutions in higher
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48 education allowing for flexible and scalable access to learning materials.[22] To
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50 investigate the potential of different CCD formats for regular curricular use, we also
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4 measured subjective learning outcomes after the intervention and correlated student
5 self-assessments with objective changes in their clinical reasoning skills.
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10 11 **Methods**

12 13 **Participants / Ethics**

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16 Initially, we recruited 106 volunteer medical students at the Medical Faculty of LMU
17 Munich. Randomisation was performed in a two-step procedure: First, we selected a
18 sample of roughly 100 enrolled students. Next, we stratified participants by creating
19 triplets on the basis of the variables age, gender, year of study, prior CCD participation
20 and performance in a knowledge application pre-test. This was done in an effort to limit
21 the risk of random misdistribution of the selected sample. From each triplet we
22 randomly assigned participants to the experimental groups. A total of 90 participants
23 eventually completed the study, 31 of them were male and 59 female. They were 20 to
24 41 years old ($M = 23$; $SD = 2.97$) and in their first to eighth clinical semester ($M = 3.5$;
25 $SD = 1.78$).
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39 The study was approved by the ethics committee of the Medical Faculty of LMU
40 Munich (approval reference no. 222-15). Written informed consent was obtained from
41 all study participants and they received a financial reimbursement of 50 Euros upon
42 completion of the trial.
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50 51 **Patient and public involvement**

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53 No patients or public were involved in this research.
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57 58 **Study design**

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4 We conducted a single-center randomised controlled trial consisting of a total of five
5 course sessions with a parallel design (see Figure 1). One week prior to the first CCD
6 session, participants were introduced to the principles of the CCD approach and the
7 sequence of this trial in an introductory session where they also took a knowledge
8 application pre-test (T_0). In the experimental phase, participants attended three weekly
9 interventional course sessions of 90 minutes each in one of the three aforementioned
10 groups with the respective CCD formats. Participants took a knowledge application
11 post-test at the end of the last experimental course session (T_1), four weeks after pre-
12 testing. A delayed knowledge application post-test was conducted two weeks after
13 completion of the interventional courses (T_2); we deliberately chose that time interval
14 to investigate the sustainability of possible effects while balancing the risk of post-
15 intervention confounding.[23]

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Insert Figure 1 about here

Materials

In all experimental groups the intervention was based on the same three, independent internal medicine cases. Chief complaints in these cases were paresthesia (first session), fever and respiratory failure (second session), and rapidly progressive respiratory failure (third session).[24-26] Cases were worked through in an iterative approach in different formats: (a) peer-moderated live case discussions in an interactive setting (Live-CCD, $n = 30$), (b) a single-learner format utilizing an interactive multimedia platform displaying video recordings of the live case discussions (Video-CCD, $n = 27$), and (c) a single-learner format in which the students worked with the original paper cases of the NEJM

(Paper-Cases, $n = 33$). The cases were prepared in a way that participants in each format were exposed to the same case information.

Procedure

In all three groups cases were presented in a specified structured manner similar to the original Clinicopathological Conferences (see Figure 2). In each format the students (“discussants”) had to fill out a form after the admission in which the case had to be summarised and a list of clinical problems and working diagnoses had to be provided. Subsequently, between discussion and summary a second case-summary had to be completed in which the final diagnostic test and the most likely diagnosis had to be proposed.

Insert Figure 2 about here

In the Live-CCD group, the case presentation was prepared beforehand by a voluntary discussant (“presenter”), who presented the facts in the admission (according to the structure shown in Figure 2). Electronic slides and flipcharts were used to transport case information. Original test results were revealed by the presenter during the discussion only when requested by the group of students. Furthermore, the presenter summarised the differential diagnosis, important pathophysiological features of the case at the end of the session and provided a short take home message. The moderating medical students (“moderator”) were recruited among previous CCD participants. They had experience in CCD moderation and had had an introductory training (two days) in higher education methods and group facilitation prior to the study. The moderator facilitated the discussion process and ensured a reasonable approach to the patient encounter (e.g. with

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4 respect to timing and hierarchy of ordered tests) in close communication with the
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6 discussants. Moreover, the moderator helped students develop their diagnostic strategy
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8 by co-evaluating their requested findings and the reasoning employed. Supervision of
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10 the correctness of medical facts and the correct diagnostic approach were ultimately
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12 granted by a clinician who could stop the discussion at any point when faulty reasoning
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14 was evident or discussants explicitly requested the facilitation of an experienced
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16 physician. The clinicians' level of involvement into the discussion was left at their own
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18 discretion. We varied the staff between each Live-CCD to minimise effects of personal
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20 teacher characteristics. Live sessions typically lasted 90 minutes and were recorded with
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22 multiple cameras.
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27 Students in the Video-CCD format worked on a single-learner multimedia workstation
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29 on which a video recording of the Live-CCD were displayed. These recordings also
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31 contained the electronic slide presentation from the Live-CCD and enabled
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33 simultaneous observation of the discussion from multiple camera angles. Participants
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35 could pause and partially skip the videos.
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39 In the Paper-Cases group participants received the case information of each CCD
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41 section sequentially (i.e. admission, discussion, summary) in a print format. In both
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43 single-learner formats students could choose their personal working speed. There was
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45 neither a prespecified minimum nor a maximum time they were required to work on the
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47 cases. In each of the three formats full access to the internet was permitted for additional
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49 information.
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Instruments

Learning outcomes with respect to clinical reasoning were measured with a knowledge application test that consisted of 29 items (i.e. a maximum of 29 points could be achieved) and was to be filled out within 45 minutes. The knowledge application test was based on instruments previously developed at the Institute for Medical Education at LMU Munich.[27-29] It comprised multiple choice items, key feature problems and problem-solving tasks, addressing the conceptual, strategic, and conditional knowledge of the participants (see Figure 3). Meta-analyses on retest effects suggest that score increase is higher for identical forms than for parallel test forms.[30] In order to limit such effects, we applied parallel forms of the knowledge application test for pre- and post-measurements (i.e. topics covered by the individual items were the same, but the items were reformulated and their order was permuted). Overall test difficulty was chosen to be high in order to avoid ceiling effects, as students from all clinical years were allowed to participate in the study. Overall test reliability was satisfactory (Cronbach's $\alpha = .71$).

Insert Figure 3 about here

Subjective learning outcomes were measured at T₁ with a short questionnaire consisting of 9 items (e.g. "I learned a lot during the CCD course", "The CCD course increased my learning motivation" or "I recommend the implementation of the CCD teaching format into the curriculum"; the full questionnaire is available as a supplementary file). Participants were asked to rate these items on a Likert scale ranging from 1 (I don't agree) to 5 (I fully agree). Reliability of the corresponding scale was good (Cronbach's $\alpha = .95$). Additionally, study participants were asked to share their

views on positive and negative aspects of the respective training format through open items at the end of the questionnaire.

Statistical Analysis

The required sample size ($N = 128$) was estimated to detect medium effect sizes with a power of 80% and a significance level of $\alpha = .05$. For between-group analyses, one-way ANOVAs were conducted with *post-hoc* Bonferroni tests for multiple comparisons.

Results

Effects of the CCD format on learning outcomes related to Clinical Reasoning

Experimental groups differed significantly with respect to the knowledge application post-test (see Table 1), $F(2,87) = 27.07$, $p = .000$, partial $\eta^2 = .384$. The Live-CCD group ($M = 14.10$; $SD = 3.32$) outperformed both the Video-CCD ($M = 11.69$; $SD = 3.34$) and the Paper-Cases group ($M = 8.5$; $SD = 2.44$). Post hoc Bonferroni tests revealed significant differences between Live-CCD and Video-CCD ($p = .011$) as well as the Paper-Cases group ($p = .000$). The difference in the knowledge application post-test between Video-CCD and the Paper-Cases group was also significant ($p = .000$).

Two weeks after course completion, the effect of the teaching format was still found in a delayed knowledge application post-test, $F(2,87) = 30.91$, $p = .000$, partial $\eta^2 = .415$. Both Live-CCD ($M = 13.36$; $SD = 3.23$) and the Video-CCD ($M = 11.84$; $SD = 2.92$) outperformed the Paper-Cases group ($M = 7.89$; $SD = 2.41$). Post hoc Bonferroni tests revealed significant differences between the Live-CCD and Paper-Cases group ($p = .000$) as well as between the Video-CCD and Paper-Cases group ($p = .000$). However,

the difference between Live-CCD and Video-CCD was not significant in the delayed knowledge application post-test ($p = .146$).

Table 1. Overview of the findings of the study.

	Teaching format					
	Live-CCD		Video-CCD		Paper-Cases	
	M	(SD)	M	(SD)	M	(SD)
Knowledge application pre-test	5.34	(1.92)	4.76	(1.90)	5.76	(2.24)
	$n = 30$		$n = 27$		$n = 33$	
Knowledge application post-test	14.10	(3.32)	11.69	(3.34)	8.50	(2.44)
	$n = 30$		$n = 27$		$n = 33$	
Delayed knowledge application post-test	13.36	(3.23)	11.84	(2.92)	7.89	(2.41)
	$n = 30$		$n = 27$		$n = 33$	
Subjective learning outcomes	4.20	(.63)	3.18	(1.24)	3.00	(.99)
	$n = 30$		$n = 27$		$n = 31$	

Effects of the CCD format on subjective learning outcomes

Experimental groups differed significantly with respect to subjective learning outcomes (see Table 1), $F(2,85) = 13.16$, $p = .000$, partial $\eta^2 = .236$. Participants of the Live-CCD group ($M = 4.20$; $SD = .63$) assigned better ratings to their course format than participants in the Video-CCD group ($M = 3.18$; $SD = 1.24$) and the Paper-Cases group ($M = 3.0$; $SD = .99$). Post hoc Bonferroni tests showed that the Live-CCD differed from the Video-CCD ($p = .001$) and the Paper-Cases group ($p = .000$) in this regard. An additional Duncan post-hoc test confirmed that the Video-CCD and the Paper-Cases group did not differ from each other in this regard ($p = .48$).

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4 To investigate the relations between the subjective assessment and the knowledge
5 application tests applied at the end and two weeks after the course, we calculated
6 correlations between the different outcome measures. Subjective learning outcomes
7 correlated on a medium level with both the knowledge application post-test ($r = .343$, n
8 = 88, $p = .001$) and the delayed knowledge application post-test ($r = .339$, $n = 88$, $p =$
9 .001).
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18 In the Live-CCD group, 83% of the students were in favour of implementing routine
19 Live-CCD into the medical curriculum. Only 45% and 31% of students from the Video-
20 CCD and Paper-Cases groups voted for an implementation of their respective course in
21 the curriculum. With respect to the open items from the subjective learning outcomes
22 questionnaire, participants from all groups praised the quality of the cases. Participants
23 from the Live-CCD group particularly valued their course format for providing an
24 opportunity to practice “diagnostic thinking” and the “focus on practice elements”. They
25 also mentioned that “you can look up theoretical knowledge, but you can’t look up
26 applied knowledge”. Students in the Video-CCD group, on the other hand, praised
27 features of the digital learning environment as they could “pause, reflect, or quickly do a
28 Google search” when watching the case discussions. However, they also criticised it
29 was not possible for them to “participate in a more active way”.
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48 **Discussion**

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51 This randomised controlled study shows that even relatively short CCD interventions
52 can lead to improved and sustainable learning outcomes with respect to clinical
53 reasoning. This provides evidence that the CCD approach, which is based on
54 Clinicopathological Conferences, is an effective teaching resource to foster clinical
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4 reasoning skills in medical students. We had hypothesised that a more interactive course
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6 format would result in an improvement of clinical reasoning skills when compared with
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8 less interactive formats. Results show that the Live-CCD indeed leads to the highest
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10 learning outcomes in medical students compared to less interactive formats. Consistent
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12 with our hypothesis, clinical reasoning skills, as measured with our knowledge
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14 application test, had the highest gain in the Live-CCD group. These positive effects of
15
16 the CCD teaching format on clinical reasoning skills proved sustainable as shown by the
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18 results in the delayed knowledge application post-test. Overall, these results are in line
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20 with a recently published study on diagnostic reasoning[31] where students who worked
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22 in pairs were more accurate in their diagnosis than individual students despite having
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24 comparable knowledge. Collaborative clinical reasoning has thus far been
25
26 underrepresented in the literature, yet seems to solve many of the educational problems
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28 regarding diagnostic errors.[32]

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34 The significant difference between the Live-CCD and the Video-CCD group can be
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36 explained by the findings of a meta-analysis that showed technology-assisted single-
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38 person learning to be inferior to group learning because of the decreased social
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40 interaction.[33] However, it is important to note that two weeks after the course,
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42 participants of the Live-CCD and Video-CCD groups did not differ significantly
43
44 anymore while both groups still clearly outperformed the Paper-Case group. In other
45
46 words, watching a video of the live case discussion was found to be more beneficial for
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48 learners regarding their clinical reasoning skills than just reading the printed cases. We
49
50 cannot rule out that Live-CCD and Video-CCD groups did not differ in the delayed
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52 knowledge application post-test due to underpowering of the study. As our trial was not
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54 designed to detect smaller effect sizes, this finding has to be treated with caution.
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4 Subjective learning outcomes suggest that students prefer the live discussion over the
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6 other formats. The subjective assessment correlated with the students' performance in
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8 both knowledge application post-tests. Additional qualitative data from the open item
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10 answers suggests that the Live-CCD format supported students in performing clinical
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12 reasoning and that the active discussion of cases was particularly valued by the students.
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18 **Generalisability**

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20 The conclusions of this study are applicable to a broader audience of medical students.
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22 The CCD approach and its respective formats can easily be implemented in routine
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24 medical education. Peer teaching courses hold the promise of being more easy to install
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26 and more easy to staff than courses led by faculty. Of course, live CCDs still come with
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28 certain personnel requirements, as faculty as well as a moderator need to be present.
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30 Extensive preparation was not necessary for the clinicians involved though as they
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32 served as facilitators and provided guidance only in situations when they were explicitly
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34 asked for their clinical judgement or when they felt that the discussion went astray.
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36 Total time requirements might still be lower compared to other teaching formats.
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38 Likewise, the implementation of a singular two-day training for moderators should not
39
40 require extensive resources. The study population consisting of students with
41
42 heterogeneous levels of clinical experience implies that the CCD is an effective teaching
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44 format not only for students at the beginning of their clinical career but also for
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46 intermediate students. On the other hand, generalisability is potentially limited as only
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48 students from one medical school participated in our study.
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Limitations of the study

There are certain limitations of this study that have to be addressed: One important limitation is the single-centre nature of this study and the relatively small sample size. Before the CCD approach can be implemented on a larger scale, a validation of our findings is therefore required. Caution is clearly warranted with the effect sizes shown in this trial, as it has been shown that effect sizes of learning intervention trials tend to be inflated compared to the effectiveness of the intervention when used in routine education.[34] Since we did not limit the time students had to work on the cases, we cannot entirely rule out that less time was spent on task in the single-learner formats and particularly the Paper-Cases group. Against this backdrop, we suggest replication to further validate the results found in this study and strengthen the outlined implications. The knowledge application test utilized in this study did not allow for a more in-depth analysis of clinical reasoning skills (i.e. a distinction of conceptual, strategic, and conditional knowledge). Larger item numbers could facilitate a reliable assessment of changes on the level of corresponding subscales. Finally, we cannot relate the underlying reasoning process with the measured knowledge gains. Further studies on clinical reasoning processes of individuals and groups are methodologically challenging but urgently needed for the advancement of a model of clinical reasoning and for improving teaching clinical reasoning.[35]

Implications for policy makers / Future research questions

Based on our findings, the CCD approach is a useful asset for medical educators to widen the range of clinical reasoning teaching tools. Live-CCD can thus be seen as a prime candidate for routine implementation in clinical reasoning curricula. Future

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4 research should aim to identify which Live-CCD elements (the roles, case contents, or
5 the course structure) contribute in which way to the improvement of clinical reasoning
6 skills in medical students. The question if and to what extent such skills are applicable
7 across domains is currently being discussed.[36] Future studies may also address the
8 issue of transfer (i.e. to what extent can clinical reasoning skills obtained in case-based
9 training later be applied to different cases?).[37] Regarding the Video-CCD, means of
10 instructional support to increase the effectiveness and interactivity of the video-based
11 format should be investigated in an attempt to exploit its full potential.
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Competing Interests

Marc Weidenbusch declares to have no conflict of interest.

Benedikt Lenzer declares to have no conflict of interest.

Maximilian Sailer declares to have no conflict of interest.

Christian Strobel declares to have no conflict of interest.

Raphael Kunisch declares to have no conflict of interest.

Jan Kiesewetter declares to have no conflict of interest.

Martin R. Fischer declares to have no conflict of interest.

Jan M. Zottmann declares to have no conflict of interest.

Author contributions

MW, BL, MF and JZ planned the study.

MW, BL and CS were responsible for data acquisition.

MW, BL, RK, JK, JZ, MF and MS analysed and interpreted the data.

MW, BL and JZ drafted and revised the manuscript, all authors contributed significant intellectual content and all authors gave final approval of the version to be published.

Data sharing statement

Dataset and detailed information about the CCD formats is available upon request.

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For peer review only

Figure legends

Figure 1: Study design. Full data sets of 90 medical students were analysed. T_0: knowledge application pre-test, T_1: knowledge application post-test, T_2: delayed knowledge application post-test.

Figure 2: Live-CCD Structure. CCD sessions are divided into three parts: In the *admission* part the presenting student shows the discussants his prepared slides (based on the original NEJM-case record), after which the group has to agree on an assessment of the patient under discussion. In the interactive *discussion* part the students prioritise the medical problems, link them to possible etiologies and order tests to further corroborate or discard differential diagnoses. After all the tests that were performed in the case record, the discussants order the putative diagnostic test. The result is disclosed along with the pathological discussion and “take home messages” on important differentials in the third part of the session. Abbreviations: CC chief complaint, HPI history of present illness, PMH past medical history, Meds medications, SH social history, FH family history, ROS review of systems, VS vital signs, PE physical examination, CMP comprehensive metabolic panel, CBC complete blood count, PT prothrombin time, PTT partial thromboplastin time, UA urine analysis, ECG electrocardiogram, CXR chest radiograph.

Figure 3: Knowledge application test. Exemplary items are shown for each of the knowledge types addressed (arrows point to the correct answers). The test included 11 items on conceptual knowledge, 9 items on strategic knowledge, and 9 items on conditional knowledge.

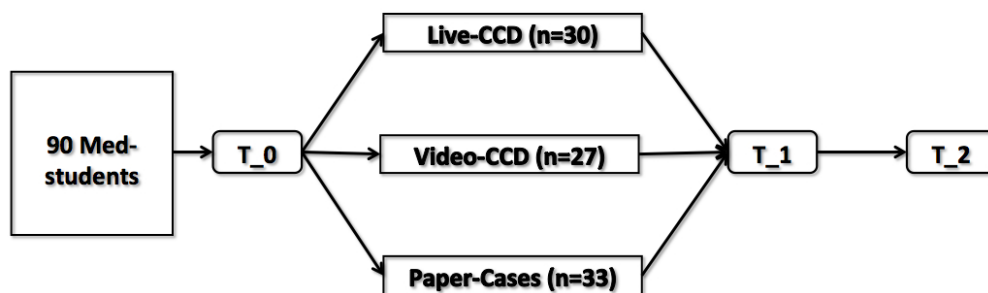


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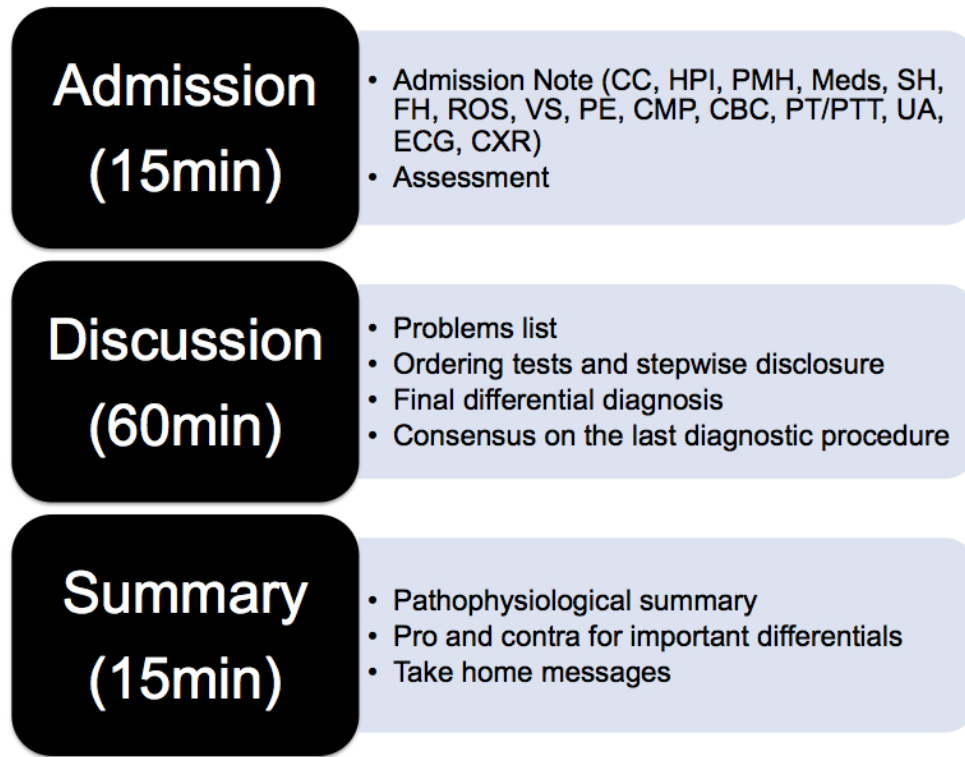


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Conceptual knowledge

- What of the following medications is a neuraminidase inhibitor?
Amantadin / Ledipasvir / Tenofovir / Dolutegravir / ➡ **Zanamivir**

Strategic knowledge

A 54 year old woman is brought into your emergency department by EMS with cough, fever and dyspnea. History taking is almost impossible because the patient is somnolent. Her vital signs are: T 39,2 °C, BP 120/80 mmHG, HF 90 bpm, AF 30/min, SpO₂ 83% on ambient air, raising to 87% with 15l O₂/min on a non-rebreather mask. PE: diffuse crackles over both lungs, peripheral cyanosis.

- What is the most pressing diagnostic or therapeutic measure?
➡ **Intubation**

Conditional knowledge

A 42 year old woman presents with a body weight of 35 kg and a BMI of 19,2. The patient tells you while weight loss was intentional in the beginning, it has now by far exceeded the desired extent. Lab values show macrocytic anemia and thrombocytopenia along with an eosinophilia of 800/μl. You suspect an infection with the fish tape worm *Diphyllobothrium latum*.

- Please elaborate what processes might underly the weight loss and the bicytopenia.
➡ **Tape worm infection causes vitamin B12 deficiency-induced bicytopenia and malnutrition because of biological competition for enteral resorption of vitamins and nutrients**

Figure 3: Knowledge application test. Exemplary items are shown for each of the knowledge types addressed (arrows point to the correct answers). The test included 11 items on conceptual knowledge, 9 items on strategic knowledge, and 9 items on conditional knowledge.

150x135mm (600 x 600 DPI)

Supplemental

Baseline data: Demographic characteristics of the study participants.

	CCD format							
	Live-CCD		Video-CCD		Paper-Cases		All formats	
	<i>n</i> = 30		<i>n</i> = 27		<i>n</i> = 33		<i>N</i> = 90	
Gender distribution								
<i>N</i> m/f	14/16		5/22		12/21		31/59	
(% f)	(53.3% f)		(81.5% f)		(63.6% f)		(65.6% f)	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)
Age	23.77	(4.09)	22.26	(1.77)	22.91	(2.40)	23.0	(2.97)
Clinical semester	3.23	(1.96)	3.41	(1.47)	3.82	(1.84)	3.50	(1.78)
High school grade	1.53	(0.36)	1.35	(0.42)	1.48	(0.68)	1.46	(0.52)
First National Board Exam								
Score	245	(30)	226	(78)	246	(30)	240	(49)
Participants with prior								
CCD experience	6	(20.0%)	6	(22.2%)	5	(15.1%)	17	(18.9%)
n (%)								

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3 *Questionnaire items (5-point Likert scale) for the assessment of subjective learning outcomes.*
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- 6 1. I perceived this CCD format as meaningful.
 - 7 2. I learned a lot during the CCD course.
 - 8 3. The CCD course increased my learning motivation.
 - 9 4. I would like to participate in this CCD format again in the future.
 - 10 5. I enjoyed the CCD course.
 - 11 6. This CCD format should be offered as part of the curriculum.
 - 12 7. I was able to follow the case discussions.
 - 13 8. Learning in the CCD format is easier for me than learning in traditional lectures or seminars.
 - 14 9. How would you rate the course overall?
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CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	1
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	2-3
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	4-7
	2b	Specific objectives or hypotheses	6-7
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	8
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	not applicable
Participants	4a	Eligibility criteria for participants	7
	4b	Settings and locations where the data were collected	7
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	8-10
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	8, 11-12
	6b	Any changes to trial outcomes after the trial commenced, with reasons	not applicable
Sample size	7a	How sample size was determined	12
	7b	When applicable, explanation of any interim analyses and stopping guidelines	not applicable
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	7
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	7
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	not applicable
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	not applicable
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those	not applicable

		assessing outcomes) and how	
	11b	If relevant, description of the similarity of interventions	not applicable
Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes	12
	12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses	12
Results			
Participant flow (a diagram is strongly recommended)	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and were analysed for the primary outcome	attached as supplemental
	13b	For each group, losses and exclusions after randomisation, together with reasons	7
Recruitment	14a	Dates defining the periods of recruitment and follow-up	not applicable
	14b	Why the trial ended or was stopped	not applicable
Baseline data	15	A table showing baseline demographic and clinical characteristics for each group	attached as supplemental
Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was by original assigned groups	13
Outcomes and estimation	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its precision (such as 95% confidence interval)	12-14
	17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended	not applicable
Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing pre-specified from exploratory	not applicable
Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)	not applicable
Discussion			
Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses	17
Generalisability	21	Generalisability (external validity, applicability) of the trial findings	16
Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence	14-16
Other information			
Registration	23	Registration number and name of trial registry	not applicable
Protocol	24	Where the full trial protocol can be accessed, if available	19
Funding	25	Sources of funding and other support (such as supply of drugs), role of funders	18

*We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials. Additional extensions are forthcoming: for those and for up to date references relevant to this checklist, see www.consort-statement.org.



CONSORT 2010 Flow Diagram

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Enrollment

Assessed for eligibility (n=106)

Excluded (n=0)
 ♦ Not meeting inclusion criteria (n=0)
 ♦ Declined to participate (n=0)
 ♦ Other reasons (n=0)

Randomised (n=106)

Allocation

Allocated to Live-CCD (n=35)
 ♦ Received allocated intervention (n=35)
 ♦ Did not receive allocated intervention (n=0)

Allocated to Video-CCD (n=34)
 ♦ Received allocated intervention (n=34)
 ♦ Did not receive allocated intervention (n=0)

Allocated to Paper-Cases (n=37)
 ♦ Received allocated intervention (n=37)
 ♦ Did not receive allocated intervention (n=0)

Follow-Up

Lost to follow-up/discontinued intervention (reasons not known) (n=5)

Lost to follow-up/discontinued intervention (reasons not known) (n=7)

Lost to follow-up/discontinued intervention (reasons not known) (n=4)

Analysis

Analysed (n=30)
 ♦ Excluded from analysis because of incomplete datasets (n=5)

Analysed (n=27)
 ♦ Excluded from analysis because of incomplete datasets (n=7)

Analysed (n=33)
 ♦ Excluded from analysis because of incomplete datasets (n=4)

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Can Clinical Case Discussions foster clinical reasoning skills in undergraduate medical education? A randomised controlled trial

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RESEARCH PAPER

**Can Clinical Case Discussions foster clinical reasoning skills in
undergraduate medical education? A randomised controlled trial**

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Keywords: undergraduate medical education, case-based learning, clinical reasoning,
social interaction, medical decision making

Abstract

Objective: Fostering clinical reasoning is a mainstay of medical education. Based on the Clinicopathological Conferences, we propose a case-based peer teaching approach called Clinical Case Discussions (CCDs) to promote the respective skills in medical students. This study compares the effectiveness of different CCD formats with varying degrees of social interaction in fostering clinical reasoning.

Design, setting, participants: A single-center randomised controlled trial with a parallel design was conducted at a German university. Study participants ($N=106$) were stratified and tested regarding their clinical reasoning skills right after CCD participation and two weeks later.

Intervention: Participants worked either within a live discussion group (Live-CCD), a group watching recordings of the live discussions (Video-CCD), or a group working with printed cases (Paper-Cases). The presentation of case information followed an admission-, discussion-, summary-sequence.

Primary and secondary outcome measures: Clinical reasoning skills were measured with a knowledge application test addressing the students' conceptual, strategic, and conditional knowledge. Additionally, subjective learning outcomes were assessed.

Results: With respect to learning outcomes, the Live-CCD group displayed the best results, followed by Video-CCD and Paper-Cases, $F(2,87)=27.07$, $p<0.001$, partial $\eta^2=0.384$. No difference was found between Live-CCD and Video-CCD groups in the delayed post-test; however, both outperformed the Paper-Cases group, $F(2,87)=30.91$, $p<0.001$, partial $\eta^2=0.415$. Regarding subjective learning outcomes, the Live-CCD received significantly better ratings than the other formats, $F(2,85)=13.16$, $p<0.001$, partial $\eta^2=0.236$.

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4 **Conclusions:** This study demonstrates that the CCD approach is an effective and
5 sustainable clinical reasoning teaching resource for medical students. Subjective
6 learning outcomes underline the importance of learner (inter-)activity in the acquisition
7 of clinical reasoning skills in the context of case-based learning. Higher efficacy of
8 more interactive formats can be attributed to positive effects of collaborative learning.
9 Future research should investigate how the Live-CCD format can further be improved
10 and how video-based CCDs can be enhanced through instructional support.
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23 **Article summary**

24 **Strengths and limitations of this study:**

- 25 • First empirical study on the implementation of Clinical Case Discussions in
26 undergraduate medical education.
- 27 • Comparison of Clinical Case Discussions with differing grades of social
28 interaction to determine their effectiveness on medical students' acquisition of
29 clinical reasoning skills by between-group analyses.
- 30 • Implementation of multidimensional and multilayered test instruments in a pre-,
31 post- and delayed post-test design to measure clinical reasoning skills by a
32 knowledge application test and self-assessment.
- 33 • The knowledge application test utilized in this study did not allow for a more in-
34 depth analysis of clinical reasoning skills (i.e. a distinction of conceptual,
35 strategic, and conditional knowledge).
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Introduction

Curriculum developers face the challenge of implementing competence-oriented frameworks such as CanMEDS (Canada), the NKLM (Germany) or PROFILES (Switzerland), including the need to train clinical reasoning skills as a medical doctor's key competence.[1-3] As such, clinical reasoning skills are crucial not only for appropriate medical decision making, but also to avoid diagnostic errors and the associated harm for both patients and healthcare systems.[4]

Case-based learning has been proposed to foster clinical reasoning skills[5] and is well accepted among students.[6] Case-based learning found an early representation in Clinicopathological Conferences (CPC, first introduced by Cannon in 1900[7]) which are practiced until today. The Clinicopathological Conferences conducted at the Massachusetts General Hospital are published on a regular basis known as the *Case Records* series of the New England Journal of Medicine. In those CPCs the “medical mystery”[8] presented by the case under discussion calls readers to think about the possible diagnosis themselves, before it is finally disclosed at the last part of the CPC. Despite the absence of definitive evidence for efficacy as a teaching method, CPCs have widely been used in medical education since the early 20th century to foster clinical reasoning.[9-11] While these CPC-Case Records reaches lots of medical readers around the world, it has been criticised as being anachronistic with a diagnosing “star (i.e. the discussant), performing, acutely aware of being the center of attention”.[12]

Case-based learning formats are embedded in a context, which is known to promote learning better than providing facts in an abstract, non-contextual form.[13] A definition found in the review by Merseth suggests three essential elements of a case: A case is real (i.e. based on a real-life situation or event); it relies on careful research and study; it

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4 is “created explicitly for discussion and seeks to include sufficient detail and
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6 information to elicit active analysis and interpretation by users”.^[14] Cases may be
7
8 represented by means of text, pictures, videos, and the like. Realism and authenticity are
9
10 varying features of cases,^[15] but particularly elaborated and authentic cases provide
11
12 increased diagnostic challenge, comprising added value for medical training.^[16]
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16 However, due to their setup, CPCs are often a passive learning situation for participants,
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18 as they listen to the discussant laying out his or her clinical reasoning on the case under
19
20 discussion. According to the ICAP framework by Chi et al.,^[17] teaching formats
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22 increase their efficacy from passive < active < constructive < interactive learning
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24 environments. Learning is enhanced when students interactively engage in discussions
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26 among each other. Accordingly, case-based learning has been found to be particularly
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28 beneficial in collaborative settings.^[15] However, another important aspect to consider
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30 in collaborative learning environments is that some students may participate passively
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32 while others contribute disproportionately much. To foster optimal learning effects,
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34 students should thus be encouraged to be interactively engaged. One prerequisite to
35
36 achieve self-guided learning in groups is a low threshold for students to come forward
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38 with their questions and participate in ensuing discussions.^[18] To this end, peer
39
40 teaching has been established as an effective tool to stimulate discussions.^[19] To make
41
42 sure peer tutors are not overwhelmed in moderating these discussions, the presence of
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44 an experienced clinician appears to be warranted^[20] in addition to a specific training of
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46 the tutors.
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53 Taken together, while traditional CPCs encompass some important dimensions of
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55 effective case-based learning environments, they are not systematically aiming at
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57 constructive or interactive learner activities that are known features of effective teaching
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4 formats.[17,21] Therefore, we introduced Clinical Case Discussions (CCD) in
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6 undergraduate medical education to account for these features. We still use the Case
7
8 Records of the Massachusetts General Hospital,[9] as these cases exemplify realistic
9
10 patient encounters and fulfill the criteria for an interactive collaborative learning process
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12 as explained above. In the CCD approach, cases are typically presented with
13
14 information until the admission of the patient to the hospital. This event is usually the
15
16 starting point of an interactive discussion phase of the group about possible diagnoses
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18 and diagnostic strategies. After all test results have been discussed, the actual diagnosis
19
20 is disclosed and the pitfalls and take-home messages of the case are summarised.
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24 To investigate the effectiveness of the CCD approach in undergraduate medical
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26 education, we designed an intervention trial and assessed clinical reasoning skills in
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28 medical students before and after *participating in live CCDs or being exposed to video*
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30 recordings of live CCDs. We compared these formats and its effects on clinical
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32 reasoning with the more traditional approach of working through written cases. When
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34 carrying out this randomised trial, we hypothesised that participation in live CCD
35
36 sessions would lead to a higher increase of clinical reasoning skills than simply reading
37
38 the cases. To better understand possible effects of the CCD learning environment with
39
40 its social components on learning outcomes, participation in live CCDs as outlined
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42 above was additionally compared to the effects of watching videos of CCDs online.
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44 This comparison also seemed relevant from an economic point of view as video-
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46 streaming of lectures and seminars are prevalent at many institutions in higher
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48 education allowing for flexible and scalable access to learning materials.[22] To
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50 investigate the potential of different CCD formats for regular curricular use, we also
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4 measured subjective learning outcomes after the intervention and correlated student
5 self-assessments with objective changes in their clinical reasoning skills.
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10 11 **Methods**

12 13 **Participants / Ethics**

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16 Initially, we recruited 106 volunteer medical students at the Medical Faculty of LMU
17 Munich. Randomisation was performed in a two-step procedure: First, we selected a
18 sample of roughly 100 enrolled students. Next, we stratified participants by creating
19 triplets on the basis of the variables age, gender, year of study, prior CCD participation
20 and performance in a knowledge application pre-test. This was done in an effort to limit
21 the risk of random misdistribution of the selected sample. From each triplet we
22 randomly assigned participants to the experimental groups. A total of 90 participants
23 eventually completed the study, 31 of them were male and 59 female. They were 20 to
24 41 years old ($M=23$; $SD=2.97$) and in their first to eighth clinical semester ($M=3.50$;
25 $SD=1.78$).
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39 The study was approved by the ethics committee of the Medical Faculty of LMU
40 Munich (approval reference no. 222-15). Written informed consent was obtained from
41 all study participants and they received a financial reimbursement of 50 Euros upon
42 completion of the trial.
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50 51 **Patient and public involvement**

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53 No patients or public were involved in this research.
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57 58 **Study design**

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4 We conducted a single-center randomised controlled trial consisting of a total of five
5 course sessions with a parallel design (see Figure 1). One week prior to the first CCD
6 session, participants were introduced to the principles of the CCD approach and the
7 sequence of this trial in an introductory session where they also took a knowledge
8 application pre-test (T_0). In the experimental phase, participants attended three weekly
9 interventional course sessions of 90 minutes each in one of the three aforementioned
10 groups with the respective CCD formats. Participants took a knowledge application
11 post-test at the end of the last experimental course session (T_1), four weeks after pre-
12 testing. A delayed knowledge application post-test was conducted two weeks after
13 completion of the interventional courses (T_2); we deliberately chose that time interval
14 to investigate the sustainability of possible effects while balancing the risk of post-
15 intervention confounding.[23]

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33 Insert Figure 1 about here

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37 **Materials**

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39 In all experimental groups the intervention was based on the same three, independent
40 internal medicine cases. Chief complaints in these cases were paresthesia (first session),
41 fever and respiratory failure (second session), and rapidly progressive respiratory failure
42 (third session).[24-26] Cases were worked through in an iterative approach in different
43 formats: (a) peer-moderated live case discussions in an interactive setting (Live-CCD,
44 $n=30$), (b) a single-learner format utilizing an interactive multimedia platform
45 displaying video recordings of the live case discussions (Video-CCD, $n=27$), and (c) a
46 single-learner format in which the students worked with the original paper cases of the
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4 NEJM (Paper-Cases, $n=33$). The cases were prepared in a way that participants in each
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6 format were exposed to the same case information.
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10 11 **Procedure**

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13 In all three groups cases were presented in a specified structured manner similar to the
14
15 original Clinicopathological Conferences (see Figure 2). In each format the students
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17 (“discussants”) had to fill out a form after the admission in which the case had to be
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19 summarised and a list of clinical problems and working diagnoses had to be provided.
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21 Subsequently, between discussion and summary a second case-summary had to be
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23 completed in which the final diagnostic test and the most likely diagnosis had to be
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25 proposed.
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31 Insert Figure 2 about here

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35 In the Live-CCD group, the case presentation was prepared beforehand by a voluntary
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37 discussant (“presenter”), who presented the facts in the admission (according to the
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39 structure shown in Figure 2). Electronic slides and flipcharts were used to transport case
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41 information. Original test results were revealed by the presenter during the discussion
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43 only when requested by the group of students. Furthermore, the presenter summarised
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45 the differential diagnosis, important pathophysiological features of the case at the end of
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47 the session and provided a short take home message. The moderating medical students
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49 (“moderator”) were recruited among previous CCD participants. They had experience in
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51 CCD moderation and had had an introductory training (two days) in higher education
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53 methods and group facilitation prior to the study. The moderator facilitated the
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55 discussion process and ensured a reasonable approach to the patient encounter (e.g. with
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4 respect to timing and hierarchy of ordered tests) in close communication with the
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6 discussants. Moreover, the moderator helped students develop their diagnostic strategy
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8 by co-evaluating their requested findings and the reasoning employed. Supervision of
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10 the correctness of medical facts and the correct diagnostic approach were ultimately
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12 granted by a clinician who could stop the discussion at any point when faulty reasoning
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14 was evident or discussants explicitly requested the facilitation of an experienced
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16 physician. The clinicians' level of involvement into the discussion was left at their own
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18 discretion. We varied the staff between each Live-CCD to minimise effects of personal
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20 teacher characteristics. Live sessions typically lasted 90 minutes and were recorded with
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22 multiple cameras.
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27 Students in the Video-CCD format worked on a single-learner multimedia workstation
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29 on which a video recording of the Live-CCD were displayed. These recordings also
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31 contained the electronic slide presentation from the Live-CCD and enabled
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33 simultaneous observation of the discussion from multiple camera angles. Participants
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35 could pause and partially skip the videos.
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39 In the Paper-Cases group participants received the case information of each CCD
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41 section sequentially (i.e. admission, discussion, summary) in a print format. In both
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43 single-learner formats students could choose their personal working speed. There was
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45 neither a prespecified minimum nor a maximum time they were required to work on the
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47 cases. In each of the three formats full access to the internet was permitted for additional
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49 information.
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Instruments

Learning outcomes with respect to clinical reasoning were measured with a knowledge application test that consisted of 29 items (i.e. a maximum of 29 points could be achieved) and was to be filled out within 45 minutes. The knowledge application test was based on instruments previously developed at the Institute for Medical Education at LMU Munich.[27-29] It comprised multiple choice items, key feature problems and problem-solving tasks, addressing the conceptual, strategic, and conditional knowledge of the participants (see Figure 3). Meta-analyses on retest effects suggest that score increase is higher for identical forms than for parallel test forms.[30] In order to limit such effects, we applied parallel forms of the knowledge application test for pre- and post-measurements (i.e. topics covered by the individual items were the same, but the items were reformulated and their order was permuted). Overall test difficulty was chosen to be high in order to avoid ceiling effects, as students from all clinical years were allowed to participate in the study. Overall test reliability was satisfactory (Cronbach's $\alpha=0.71$).

Insert Figure 3 about here

Subjective learning outcomes were measured at T₁ with a short questionnaire consisting of 9 items (e.g. "I learned a lot during the CCD course", "The CCD course increased my learning motivation" or "I recommend the implementation of the CCD teaching format into the curriculum"; the full questionnaire is available as a supplementary file). Participants were asked to rate these items on a Likert scale ranging from 1 (I don't agree) to 5 (I fully agree). Reliability of the corresponding scale was good (Cronbach's $\alpha=0.95$). Additionally, study participants were asked to share their

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4 views on positive and negative aspects of the respective training format through open
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6 items at the end of the questionnaire.
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10 11 **Statistical Analysis**

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13 The required sample size ($N=128$) was estimated to detect medium effect sizes with a
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15 power of 80% and a significance level of $\alpha=0.05$. For between-group analyses, one-way
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17 ANOVAs were conducted with *post-hoc* Bonferroni tests for multiple comparisons.
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22 23 **Results**

24 25 **Effects of the CCD format on learning outcomes related to Clinical Reasoning**

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27 Experimental groups differed significantly with respect to the knowledge application
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29 post-test (see Table 1), $F(2,87)=27.07$, $p<0.001$, partial $\eta^2=0.384$. The Live-CCD group
30
31 ($M=14.10$; $SD=3.32$) outperformed both the Video-CCD ($M=11.69$; $SD=3.34$) and the
32
33 Paper-Cases group ($M=8.50$; $SD=2.44$). Post hoc Bonferroni tests revealed significant
34
35 differences between Live-CCD and Video-CCD ($p=0.011$) as well as the Paper-Cases
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37 group ($p<0.001$). The difference in the knowledge application post-test between Video-
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39 CCD and the Paper-Cases group was also significant ($p<0.001$).
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44 Two weeks after course completion, the effect of the teaching format was still found in
45
46 a delayed knowledge application post-test, $F(2,87)=30.91$, $p<0.001$, partial $\eta^2=0.415$.
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48 Both Live-CCD ($M=13.36$; $SD=3.23$) and the Video-CCD ($M=11.84$; $SD=2.92$)
49
50 outperformed the Paper-Cases group ($M=7.89$; $SD=2.41$). Post hoc Bonferroni tests
51
52 revealed significant differences between the Live-CCD and Paper-Cases group
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54 ($p<0.001$) as well as between the Video-CCD and Paper-Cases group ($p<0.001$).
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However, the difference between Live-CCD and Video-CCD was not significant in the delayed knowledge application post-test ($p=0.146$).

Table 1. Overview of the findings of the study.

	Teaching format					
	Live-CCD		Video-CCD		Paper-Cases	
	M	(SD)	M	(SD)	M	(SD)
Knowledge application pre-test	5.34	(1.92)	4.76	(1.90)	5.76	(2.24)
	$n=30$		$n=27$		$n=33$	
Knowledge application post-test	14.10	(3.32)	11.69	(3.34)	8.50	(2.44)
	$n=30$		$n=27$		$n=33$	
Delayed knowledge application post-test	13.36	(3.23)	11.84	(2.92)	7.89	(2.41)
	$n=30$		$n=27$		$n=33$	
Subjective learning outcomes	4.20	(0.63)	3.18	(1.24)	3.00	(0.99)
	$n=30$		$n=27$		$n=31$	

Effects of the CCD format on subjective learning outcomes

Experimental groups differed significantly with respect to subjective learning outcomes (see Table 1), $F(2,85)=13.16$, $p<0.001$, partial $\eta^2=0.236$. Participants of the Live-CCD group ($M=4.20$; $SD=0.63$) assigned better ratings to their course format than participants in the Video-CCD group ($M=3.18$; $SD=1.24$) and the Paper-Cases group ($M=3.00$; $SD=0.99$). Post hoc Bonferroni tests showed that the Live-CCD differed from the Video-CCD ($p=0.001$) and the Paper-Cases group ($p<0.001$) in this regard. An additional Duncan post-hoc test confirmed that the Video-CCD and the Paper-Cases group did not differ from each other in this regard ($p=0.48$).

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4 To investigate the relations between the subjective assessment and the knowledge
5 application tests applied at the end and two weeks after the course, we calculated
6 correlations between the different outcome measures. Subjective learning outcomes
7 correlated on a medium level with both the knowledge application post-test ($r=0.343$,
8 $n=88$, $p=0.001$) and the delayed knowledge application post-test ($r=0.339$, $n=88$,
9 $p=0.001$).

10
11 In the Live-CCD group, 83% of the students were in favour of implementing routine
12 Live-CCD into the medical curriculum. Only 45% and 31% of students from the Video-
13 CCD and Paper-Cases groups voted for an implementation of their respective course in
14 the curriculum. With respect to the open items from the subjective learning outcomes
15 questionnaire, participants from all groups praised the quality of the cases. Participants
16 from the Live-CCD group particularly valued their course format for providing an
17 opportunity to practice “diagnostic thinking” and the “focus on practice elements”. They
18 also mentioned that “you can look up theoretical knowledge, but you can’t look up
19 applied knowledge”. Students in the Video-CCD group, on the other hand, praised
20 features of the digital learning environment as they could “pause, reflect, or quickly do a
21 Google search” when watching the case discussions. However, they also criticised it
22 was not possible for them to “participate in a more active way”.

48 Discussion

49
50 This randomised controlled study shows that even relatively short CCD interventions
51 can lead to improved and sustainable learning outcomes with respect to clinical
52 reasoning. This provides evidence that the CCD approach, which is based on
53 Clinicopathological Conferences, is an effective teaching resource to foster clinical
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4 reasoning skills in medical students. We had hypothesised that a more interactive course
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6 format would result in an improvement of clinical reasoning skills when compared with
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8 less interactive formats. Results show that the Live-CCD indeed leads to the highest
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10 learning outcomes in medical students compared to less interactive formats. Consistent
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12 with our hypothesis, clinical reasoning skills, as measured with our knowledge
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14 application test, had the highest gain in the Live-CCD group. These positive effects of
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16 the CCD teaching format on clinical reasoning skills proved sustainable as shown by the
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18 results in the delayed knowledge application post-test. Overall, these results are in line
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20 with a recently published study on diagnostic reasoning[31] where students who worked
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22 in pairs were more accurate in their diagnosis than individual students despite having
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24 comparable knowledge. Collaborative clinical reasoning has thus far been
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26 underrepresented in the literature, yet seems to solve many of the educational problems
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28 regarding diagnostic errors.[32]

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34 The significant difference between the Live-CCD and the Video-CCD group can be
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36 explained by the findings of a meta-analysis that showed technology-assisted single-
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38 person learning to be inferior to group learning because of the decreased social
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40 interaction.[33] However, it is important to note that two weeks after the course,
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42 participants of the Live-CCD and Video-CCD groups did not differ significantly
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44 anymore while both groups still clearly outperformed the Paper-Case group. In other
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46 words, watching a video of the live case discussion was found to be more beneficial for
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48 learners regarding their clinical reasoning skills than just reading the printed cases. We
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50 cannot rule out that Live-CCD and Video-CCD groups did not differ in the delayed
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52 knowledge application post-test due to underpowering of the study. As our trial was not
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54 designed to detect smaller effect sizes, this finding has to be treated with caution.
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4 Subjective learning outcomes suggest that students prefer the live discussion over the
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6 other formats. The subjective assessment correlated with the students' performance in
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8 both knowledge application post-tests. Additional qualitative data from the open item
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10 answers suggests that the Live-CCD format supported students in performing clinical
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12 reasoning and that the active discussion of cases was particularly valued by the students.
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18 **Generalisability**

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20 The conclusions of this study are applicable to a broader audience of medical students.
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22 The CCD approach and its respective formats can easily be implemented in routine
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24 medical education. Peer teaching courses hold the promise of being more easy to install
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26 and more easy to staff than courses led by faculty. Of course, live CCDs still come with
27
28 certain personnel requirements, as faculty as well as a moderator need to be present.
29
30 Extensive preparation was not necessary for the clinicians involved though as they
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32 served as facilitators and provided guidance only in situations when they were explicitly
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34 asked for their clinical judgement or when they felt that the discussion went astray.
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36 Total time requirements might still be lower compared to other teaching formats.
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38 Likewise, the implementation of a singular two-day training for moderators should not
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40 require extensive resources. The study population consisting of students with
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42 heterogeneous levels of clinical experience implies that the CCD is an effective teaching
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44 format not only for students at the beginning of their clinical career but also for
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46 intermediate students. On the other hand, generalisability is potentially limited as only
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48 students from one medical school participated in our study.
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Limitations of the study

There are certain limitations of this study that have to be addressed: One important limitation is the single-centre nature of this study and the relatively small sample size. Before the CCD approach can be implemented on a larger scale, a validation of our findings is therefore required. Caution is clearly warranted with the effect sizes shown in this trial, as it has been shown that effect sizes of learning intervention trials tend to be inflated compared to the effectiveness of the intervention when used in routine education.[34] Since we did not limit the time students had to work on the cases, we cannot entirely rule out that less time was spent on task in the single-learner formats and particularly the Paper-Cases group. Against this backdrop, we suggest replication to further validate the results found in this study and strengthen the outlined implications. The knowledge application test utilized in this study did not allow for a more in-depth analysis of clinical reasoning skills (i.e. a distinction of conceptual, strategic, and conditional knowledge). Larger item numbers could facilitate a reliable assessment of changes on the level of corresponding subscales. Finally, we cannot relate the underlying reasoning process with the measured knowledge gains. Further studies on clinical reasoning processes of individuals and groups are methodologically challenging but urgently needed for the advancement of a model of clinical reasoning and for improving teaching clinical reasoning.[35]

Implications for policy makers / Future research questions

Based on our findings, the CCD approach is a useful asset for medical educators to widen the range of clinical reasoning teaching tools. Live-CCD can thus be seen as a prime candidate for routine implementation in clinical reasoning curricula. Future

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4 research should aim to identify which Live-CCD elements (the roles, case contents, or
5 the course structure) contribute in which way to the improvement of clinical reasoning
6 skills in medical students. The question if and to what extent such skills are applicable
7 across domains is currently being discussed.[36] Future studies may also address the
8 issue of transfer (i.e. to what extent can clinical reasoning skills obtained in case-based
9 training later be applied to different cases?).[37] Regarding the Video-CCD, means of
10 instructional support to increase the effectiveness and interactivity of the video-based
11 format should be investigated in an attempt to exploit its full potential.
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27 **Acknowledgements**

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30 evaluation, Thomas Brendel and Thomas Bischoff for help with the video production
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36 wishes to express special thanks to Bernd Gansbacher for introduction to CCDs.
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53 of Munich (Lehre@LMU).
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Competing Interests

Marc Weidenbusch declares to have no conflict of interest.

Benedikt Lenzer declares to have no conflict of interest.

Maximilian Sailer declares to have no conflict of interest.

Christian Strobel declares to have no conflict of interest.

Raphael Kunisch declares to have no conflict of interest.

Jan Kiesewetter declares to have no conflict of interest.

Martin R. Fischer declares to have no conflict of interest.

Jan M. Zottmann declares to have no conflict of interest.

Author contributions

MW, BL, MF and JZ planned the study.

MW, BL and CS were responsible for data acquisition.

MW, BL, RK, JK, JZ, MF and MS analysed and interpreted the data.

MW, BL and JZ drafted and revised the manuscript, all authors contributed significant intellectual content and all authors gave final approval of the version to be published.

Data sharing statement

Dataset and detailed information about the CCD formats is available upon request.

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For peer review only

Figure legends

Figure 1: Study design. Full data sets of 90 medical students were analysed. T_0: knowledge application pre-test, T_1: knowledge application post-test, T_2: delayed knowledge application post-test.

Figure 2: Live-CCD Structure. CCD sessions are divided into three parts: In the *admission* part the presenting student shows the discussants his prepared slides (based on the original NEJM-case record), after which the group has to agree on an assessment of the patient under discussion. In the interactive *discussion* part the students prioritise the medical problems, link them to possible etiologies and order tests to further corroborate or discard differential diagnoses. After all the tests that were performed in the case record, the discussants order the putative diagnostic test. The result is disclosed along with the pathological discussion and “take home messages” on important differentials in the third part of the session. Abbreviations: CC chief complaint, HPI history of present illness, PMH past medical history, Meds medications, SH social history, FH family history, ROS review of systems, VS vital signs, PE physical examination, CMP comprehensive metabolic panel, CBC complete blood count, PT prothrombin time, PTT partial thromboplastin time, UA urine analysis, ECG electrocardiogram, CXR chest radiograph.

Figure 3: Knowledge application test. Exemplary items are shown for each of the knowledge types addressed (arrows point to the correct answers). The test included 11 items on conceptual knowledge, 9 items on strategic knowledge, and 9 items on conditional knowledge.

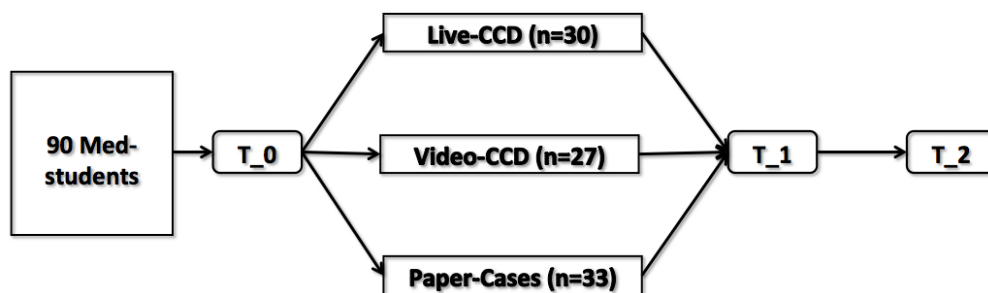


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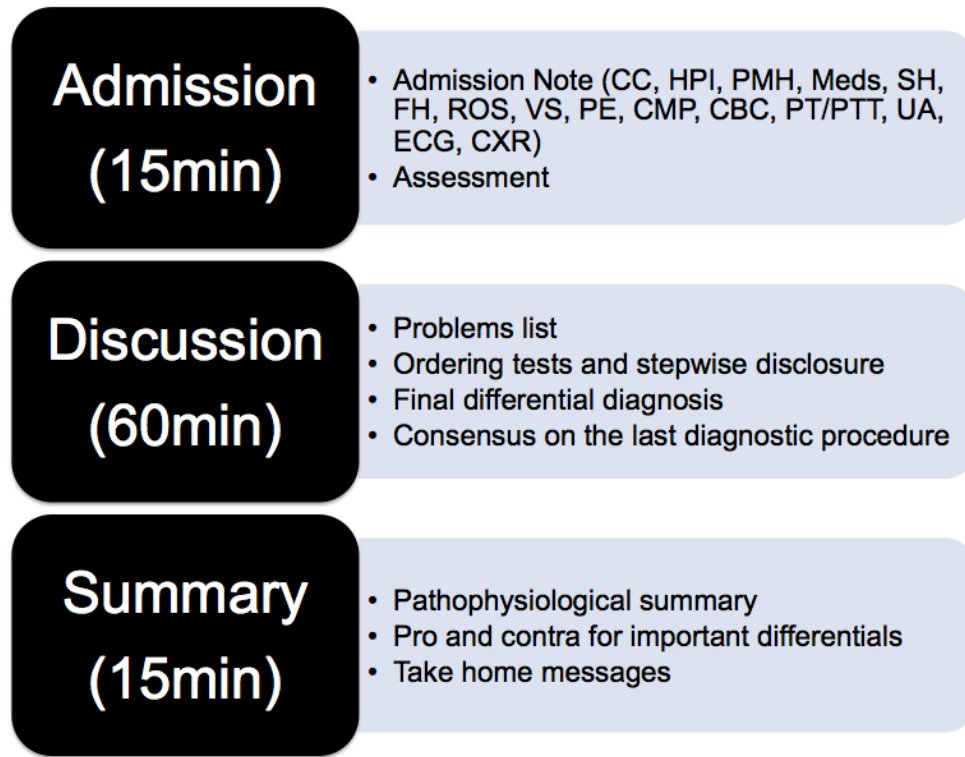


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Conceptual knowledge

- What of the following medications is a neuraminidase inhibitor?
Amantadin / Ledipasvir / Tenofovir / Dolutegravir / ➡ **Zanamivir**

Strategic knowledge

A 54 year old woman is brought into your emergency department by EMS with cough, fever and dyspnea. History taking is almost impossible because the patient is somnolent. Her vital signs are: T 39,2 °C, BP 120/80 mmHG, HF 90 bpm, AF 30/min, SpO₂ 83% on ambient air, raising to 87% with 15l O₂/min on a non-rebreather mask. PE: diffuse crackles over both lungs, peripheral cyanosis.

- What is the most pressing diagnostic or therapeutic measure?
➡ **Intubation**

Conditional knowledge

A 42 year old woman presents with a body weight of 35 kg and a BMI of 19,2. The patient tells you while weight loss was intentional in the beginning, it has now by far exceeded the desired extent. Lab values show macrocytic anemia and thrombocytopenia along with an eosinophilia of 800/μl. You suspect an infection with the fish tape worm *Diphyllobothrium latum*.

- Please elaborate what processes might underly the weight loss and the bicytopenia.
➡ **Tape worm infection causes vitamin B12 deficiency-induced bicytopenia and malnutrition because of biological competition for enteral resorption of vitamins and nutrients**

Figure 3: Knowledge application test. Exemplary items are shown for each of the knowledge types addressed (arrows point to the correct answers). The test included 11 items on conceptual knowledge, 9 items on strategic knowledge, and 9 items on conditional knowledge.

150x135mm (600 x 600 DPI)

Supplemental

Baseline data: Demographic characteristics of the study participants.

	CCD format							
	Live-CCD		Video-CCD		Paper-Cases		All formats	
	<i>n</i> = 30		<i>n</i> = 27		<i>n</i> = 33		<i>N</i> = 90	
Gender distribution								
<i>N</i> m/f	14/16		5/22		12/21		31/59	
(% f)	(53.3% f)		(81.5% f)		(63.6% f)		(65.6% f)	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)
Age	23.77	(4.09)	22.26	(1.77)	22.91	(2.40)	23.0	(2.97)
Clinical semester	3.23	(1.96)	3.41	(1.47)	3.82	(1.84)	3.50	(1.78)
High school grade	1.53	(0.36)	1.35	(0.42)	1.48	(0.68)	1.46	(0.52)
First National Board Exam								
Score	245	(30)	226	(78)	246	(30)	240	(49)
Participants with prior								
CCD experience	6	(20.0%)	6	(22.2%)	5	(15.1%)	17	(18.9%)
<i>n</i> (%)								

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3 *Questionnaire items (5-point Likert scale) for the assessment of subjective learning outcomes.*
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- 6 1. I perceived this CCD format as meaningful.
 - 7 2. I learned a lot during the CCD course.
 - 8 3. The CCD course increased my learning motivation.
 - 9 4. I would like to participate in this CCD format again in the future.
 - 10 5. I enjoyed the CCD course.
 - 11 6. This CCD format should be offered as part of the curriculum.
 - 12 7. I was able to follow the case discussions.
 - 13 8. Learning in the CCD format is easier for me than learning in traditional lectures or seminars.
 - 14 9. How would you rate the course overall?
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CONSORT 2010 Flow Diagram

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Enrollment

Assessed for eligibility (n=106)

Excluded (n=0)
 ♦ Not meeting inclusion criteria (n=0)
 ♦ Declined to participate (n=0)
 ♦ Other reasons (n=0)

Randomised (n=106)

Allocation

Allocated to Live-CCD (n=35)
 ♦ Received allocated intervention (n=35)
 ♦ Did not receive allocated intervention (n=0)

Allocated to Video-CCD (n=34)
 ♦ Received allocated intervention (n=34)
 ♦ Did not receive allocated intervention (n=0)

Allocated to Paper-Cases (n=37)
 ♦ Received allocated intervention (n=37)
 ♦ Did not receive allocated intervention (n=0)

Follow-Up

Lost to follow-up/discontinued intervention (reasons not known) (n=5)

Lost to follow-up/discontinued intervention (reasons not known) (n=7)

Lost to follow-up/discontinued intervention (reasons not known) (n=4)

Analysis

Analysed (n=30)
 ♦ Excluded from analysis because of incomplete datasets (n=5)

Analysed (n=27)
 ♦ Excluded from analysis because of incomplete datasets (n=7)

Analysed (n=33)
 ♦ Excluded from analysis because of incomplete datasets (n=4)



CONSORT 2010 checklist of information to include when reporting a randomised trial*

Section/Topic	Item No	Checklist item	Reported on page No
Title and abstract			
	1a	Identification as a randomised trial in the title	1
	1b	Structured summary of trial design, methods, results, and conclusions (for specific guidance see CONSORT for abstracts)	2-3
Introduction			
Background and objectives	2a	Scientific background and explanation of rationale	4-7
	2b	Specific objectives or hypotheses	6-7
Methods			
Trial design	3a	Description of trial design (such as parallel, factorial) including allocation ratio	8
	3b	Important changes to methods after trial commencement (such as eligibility criteria), with reasons	not applicable
Participants	4a	Eligibility criteria for participants	7
	4b	Settings and locations where the data were collected	7
Interventions	5	The interventions for each group with sufficient details to allow replication, including how and when they were actually administered	8-10
Outcomes	6a	Completely defined pre-specified primary and secondary outcome measures, including how and when they were assessed	8, 11-12
	6b	Any changes to trial outcomes after the trial commenced, with reasons	not applicable
Sample size	7a	How sample size was determined	12
	7b	When applicable, explanation of any interim analyses and stopping guidelines	not applicable
Randomisation:			
Sequence generation	8a	Method used to generate the random allocation sequence	7
	8b	Type of randomisation; details of any restriction (such as blocking and block size)	7
Allocation concealment mechanism	9	Mechanism used to implement the random allocation sequence (such as sequentially numbered containers), describing any steps taken to conceal the sequence until interventions were assigned	not applicable
Implementation	10	Who generated the random allocation sequence, who enrolled participants, and who assigned participants to interventions	not applicable
Blinding	11a	If done, who was blinded after assignment to interventions (for example, participants, care providers, those	not applicable

1		assessing outcomes) and how	
2	11b	If relevant, description of the similarity of interventions	not applicable
3	Statistical methods	12a	Statistical methods used to compare groups for primary and secondary outcomes
4		12b	Methods for additional analyses, such as subgroup analyses and adjusted analyses
5			
6	Results		
7	Participant flow (a	13a	For each group, the numbers of participants who were randomly assigned, received intended treatment, and
8	diagram is strongly		were analysed for the primary outcome
9	recommended)	13b	For each group, losses and exclusions after randomisation, together with reasons
10			
11	Recruitment	14a	Dates defining the periods of recruitment and follow-up
12		14b	Why the trial ended or was stopped
13	Baseline data	15	A table showing baseline demographic and clinical characteristics for each group
14			
15			
16	Numbers analysed	16	For each group, number of participants (denominator) included in each analysis and whether the analysis was
17			by original assigned groups
18	Outcomes and	17a	For each primary and secondary outcome, results for each group, and the estimated effect size and its
19	estimation		precision (such as 95% confidence interval)
20		17b	For binary outcomes, presentation of both absolute and relative effect sizes is recommended
21			
22	Ancillary analyses	18	Results of any other analyses performed, including subgroup analyses and adjusted analyses, distinguishing
23			pre-specified from exploratory
24			
25	Harms	19	All important harms or unintended effects in each group (for specific guidance see CONSORT for harms)
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27	Discussion		
28	Limitations	20	Trial limitations, addressing sources of potential bias, imprecision, and, if relevant, multiplicity of analyses
29	Generalisability	21	Generalisability (external validity, applicability) of the trial findings
30	Interpretation	22	Interpretation consistent with results, balancing benefits and harms, and considering other relevant evidence
31			
32	Other information		
33	Registration	23	Registration number and name of trial registry
34	Protocol	24	Where the full trial protocol can be accessed, if available
35	Funding	25	Sources of funding and other support (such as supply of drugs), role of funders
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39 *We strongly recommend reading this statement in conjunction with the CONSORT 2010 Explanation and Elaboration for important clarifications on all the items. If relevant, we also
40 recommend reading CONSORT extensions for cluster randomised trials, non-inferiority and equivalence trials, non-pharmacological treatments, herbal interventions, and pragmatic trials.
41 Additional extensions are forthcoming: for those and for up to date references relevant to this checklist, see www.consort-statement.org.