Clinical reasoning pattern used in oral health problem solving – A case study in Indonesian undergraduate dental student

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Research Article

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Abstract

Background: Health professionals in carrying out clinical practice are known to use various combinations of knowledge and skills, such as critical thinking, clinical reasoning, clinical judgment, problem-solving, and decision-making. Most of these skills are acquired during undergraduate education, clinical training and honed through professional practice.

Aims: This study aims to observe the clinical reasoning patterns of undergraduate dental students when solving oral health problems from hypothetical cases. Furthermore, assessing their structure of knowledge through a concept map defined by a SOLO taxonomy.

Material and method: This qualitative study employed the think-aloud method and the result was assessed through verbal protocol analyses. Five respondents from the final year dental undergraduate student were agreed to participate. A unique hypothetical clinical scenario was used as a trigger. The audio data were transcribed, interpreted, and categorized as a clinical reasoning pattern; and the concept maps created were assessed by SOLO Taxonomy as knowledge structures.

Result: A hypothetico-deductive, an elaborated hypothetico-deductive, and an inductive or deductive reasoning model were found to be applied by the participants when solving problems. The reasoning used reflects the knowledge possessed. The variability of the structure of knowledge assessed by the concept map reflected the acquired knowledge during the pedagogical stage, which in turn have an effect on clinical reasoning patterns.

Conclusion: It concluded that undergraduate dental student applies clinical reasoning patterns according to their level of knowledge structure. It is suggested to improve dental education, whether curriculum, teaching and learning methods, instructional methods, or dental environment, which emphasize critical thinking and clinical reasoning in order to provide optimal dental health services.

A. Introduction

Clinical reasoning is an essential component of health care professional practice ^[1, 2]. It can be defined as a skill, process, or outcome ^[3], which enabling clinicians to identify, collect and process information, determine diagnoses and make an accurate decisions about treatment options ^[4-6]. Diagnostic errors can be minimized by implementing appropriate clinical reasoning strategies, which in turn affect the improvement of patient outcomes and safety ^[7]. Research to develop and assess clinical reasoning has long been conducted in the medical profession ^[8, 9], followed by nursing and related health professions. From these various studies, it is revealed that every healthcare profession has distinctive and unique clinical reasoning when solving problems and making clinical decisions ^[10-12]. The clinical reasoning is used and applied according to the problem space of each profession ^[13-15].

B. Background

1. The definition of clinical reasoning

Clinical reasoning is a way and strategy of thinking and decision-making processes, and considered to foster clinical practice and competence^[16, 17]. Clinical reasoning varies across healthcare professions, as it encompasses a set of problem spaces, defined by the clinician's unique framework of reference, workplace, practice model and patient context^[18]. Clinical reasoning involves prudent action in the sense of taking the best course of action according to a specific context, professional action in making decisions and ethical, accountable and self-regulatory behavior; and person-centered who shows respect and is able to collaborate with clients, caregivers, and colleagues^[1]. Every health professional engages in it by gathering and synthesizing clinical evidence; generating hypotheses; and formulating an impression, decisive prognosis and diagnosis, eventually determining treatment, care, and/or management plan^[2, 19–21]. Clinical reasoning in medical practice is currently dominance by two theoretical frameworks, as the process and structural paradigm^[22, 23].

2. The process paradigm of clinical reasoning

The process paradigm comprises cognitive processes involved in clinical decision making and the structural paradigm connected to knowledge storage and recalled from memory. The cognitive processes involved in clinical reasoning paradigm emphasized on clinical judgment as intuitive and analytical approach^[19, 24]. The process of clinical reasoning varied, such as hypothetico-deductive model^[25], dual processing theory of reasoning^[22, 23], heuristic reasoning^[26], Bayesian clinical reasoning^[16, 27], forward (data-driven) reasoning^[28], backward (hypothesis-driven) reasoning^[2, 13, 29], illness scripts^[8, 19, 30], elaborated hypothetico-deductive model^[28], dual coding theory^[31], schema induction^[32, 33], and pattern recognition^[20, 34]. The process of reasoning can be determined by analyzing the content of transcription result from think aloud methods, contrasting and comparing with known clinical reasoning pattern or model^[35–37].

3. The structural paradigm of clinical reasoning

Clinical reasoning as a structural paradigm relies on how clinicians acquire, process, store and use medical knowledge to solve problems and make clinical decisions^[38]. The development of clinical reasoning rests on conceptual and procedural knowledge and is honed with clinical experience^[39–41]. In previous studies it has been shown that problem solving, judgment and clinical decision making are entrenched in how previously acquired knowledge is obtained, stored and recalled^[28, 40, 42]. Furthermore, the studies of the structure and application of knowledge in medical problem-solving across levels of expertise led to introductions of categories and prototypes, schemas, instance, semantic qualifiers and illness scripts as explanations of the differences between diagnostic reasoning of novice and expert physicians^[32, 43–46].

The structured of knowledge in memory can be measured by an assessment instrument^[47], concept or conduct test^[48] or knowledge survey^[49]. Knowledge structure seen from its acquisition can be assessed

in a formative or summative way. Formative assessment is intended to guide upcoming learning, provide reassurance, promote reflection, and shape values, while summative assessment refers to a comprehensive valuation of competence, suitability for practice, or qualifications for progress to a higher level of responsibility ^[47]. Concept or conduct test are methods used to determine the students' ability to complete certain tasks or demonstrate mastery of a skill or knowledge of content ^[48]. Knowledge Surveys consist of a series of questions that cover the full content of a course ^[49].

One of concept test is SOLO (Structure Of Learning Outcomes) Taxonomy ^[50, 51], which originally developed by Biggs and Collis in 1982. It provides descriptions of the structural organization of knowledge. The SOLO Taxonomy differentiate levels and content of knowledge, as P (Pre-structural), U (Unistructural), M (Multi-structural), R (Relational) and EA (Extended abstract). Boulton-Lewis ^[52] compared written responses, categorized according to SOLO, with concept maps as an alternative way for students to demonstrate their knowledge and structural organization of course content. There was 75% agreement between SOLO levels for concept maps and written material at the end of the subject. The use of the SOLO Taxonomy regarded as the only one way for assessing the extent of a student's content knowledge in a discipline and of its structural organization ^[51].

C. Benefi

The pedagogical stage is the most important basic step in dental education in obtaining various conceptual dan procedural knowledge. Knowledge is acquired gradually starting with basic and biomedical science, simple and advanced procedural knowledge and finally enriched with clinical experience. The knowledge structured in memory plays an important role in the retrieval of this knowledge when solving clinical problems. Observation of structures of knowledge in the memory of undergraduate students can help dental educators identify errors or inaccuracies in clinical reasoning.

D. Aim

This study aims to observe the clinical reasoning patterns of undergraduate dental students when solving oral health problems from hypothetical cases. Furthermore, assessing the structure of knowledge acquired during pedagogical stage through a concept map defined by a SOLO taxonomy.

E. Material And Method

The research protocol was prepared in accordance to the Declaration of Helsinki on the ethical principles of research involving human subjects, and having met the ethical eligibility from Medical and Health Research Ethics Committee (MHREC), Faculty of Medicine, Public Health, and Nursing University of Gadjah Mada on October, 11 2019 (No: KE/FK/1183/EC/2019). The research is carried out after getting approval from the Faculty of Dentistry, University of Gadjah Mada, Yogyakarta Indonesia (No.11709/UN1/FKG.1/Set.KGI/ LT/2019). The research was conducted in January 2020. Clinical reasoning ability was determined by verbal protocol analysis with the think aloud method.

1. Participant

The research samples were selected purposively, consisting of five participants from the final year dental undergraduate student, the University of Gadjah Mada, Yogyakarta, Indonesia. They were asked to read the aims and methods of the study prior to recruitment. Only those who signed the informed consent participated in the study. All of the participants had already finished their pedagogical phase. All participants are female students from the same entrance year (2015/2016), with the age of about 22-23 years-old. Participants' academic abilities are varied, with 3 participants were an average student with a mean GPA <3, a participant was good student with a GPA between 3-3.5 and the other was an excellent student with a GPA > 3.5.

2. Hypothetical clinical cases.

A single hypothetical clinical case was built as a trigger for clinical problem-solving and decision-making skills. Stability and fidelity of the observed results can be better obtained through a single hypothetical clinical case^[53]. The clinical findings of a hypothetical case were compiled in a "patient file" format, which was arranged sequentially from the history, clinical examination and additional investigations. The hypothetical clinical cases can be seen in appendix A. Several diagnoses can be determined based on this hypothetical clinical case. Sore mouth or oral pain as a main complaint can lead to mucosal lesions with various form, ranging from atrophic lesions, erosions, fissures to ulceration. Solving the problem will lead to several possible diagnoses, because these oral lesions have various possible etiopathogenesis. Furthermore, one of the most likely diagnoses will lead to clinical decision making, such as treatment or management of oral complaints.

3. The acquisition data through verbal or think aloud protocol.

Data acquisition were obtained through in-depth interviews guided by semi-structured questions. Observation and data collection were carried out individually by previously trained research assistants on a predetermined schedule. Interviews were conducted in a private room away from noise and crowds. After completed the informed consent, the participant asked to read the instruction carefully. The hypothetical clinical cases were given to the participants, later the research assistant questioned them based on interviews guidance. This guidance is intended to ensure uniformity of interviews for all participants. Audio recording and notes were made during the interview. At the end of the interview, the participants were asked to draw a concept map as a summary of their understanding of a hypothetical clinical case.

4. The transcription of an audio to text.

The recorded data were transcribed verbatim for further analysis through 'oTranscribe'; a free web-based application designed to obtain of transcribing recorded interviews (<https://otranscribe.com/>).

5. The determination of clinical reasoning pattern

There are not many clinical reasoning patterns used by undergraduate dental students. The most frequently revealed in clinical problem-solving research were hypothetico-deductive or elaborated hypothetico-deductive model, forward or backward reasoning model or in combination, pattern recognition and pattern recognition through scripts ^[1,16,34,54-56]. This study applies a predetermined content analysis, with theory or relevant research findings as guidance for initial codes. The transcribed data are thoroughly reviewed and interpreted meticulously to identify clinical reasoning pattern. The model of clinical reasoning from each case study or participant determined as if they fulfilled the accepted definition (Table 1).

6. The determination of structure of knowledge in memory

Concept mapping regarded as a cognitive activity that has been used to understand how learning changes a learner's cognitive structure of knowledge. It is composed of nodes, which represent concepts, and the links that connect between concepts. New knowledge is stored constructively by involving previous knowledge; thus, concept mapping is a process of creative activity in which learners exert a conscious effort to explain meaning by identifying key concepts and relationships, and relating them to existing knowledge structures and frameworks ^[57]. The SOLO taxonomy consists of five levels of sophistication, with the lower levels' emphasis on quantity or the amount the learner knows; while the higher levels focus on the integration of the details into a structural pattern and the development of relationships between the details along with other concepts outside the learning domain (Table 2).

The SOLO taxonomy can assist educators and researchers in a systematic way to identify levels student performance when mastering new learning taxonomy ^[50,51,58]. Participants' concept maps were analyzed and classified according to the different levels of SOLO taxonomy.

F. Result

As noted in the title, these articles reported and review five written data from undergraduate dental students when solving a hypothetical case. The transcribed data will be explored and discussed as a case study, one of the qualitative research methods. The case studies can be used to explore a phenomenon in a particular context through various data sources ^[59]. In this observation, the phenomenon that is being explored is the clinical reasoning pattern in the context of oral health problems and diseases. The data source was obtained by verbal protocol through think-aloud method, where students as a source of information had to verbally reveal what was on their mind when asked to solve clinical problems from a hypothetical scenario. In this way, it can be seen how students use their structure

of knowledge to solve problems. the course of clinical data analysis to the determination of the diagnosis is considered as a pattern of clinical reasoning. Initial response of each participant to clinical data while presented to clinical problems were reflected the cognitive ability or knowledge.

The results of some of the thoughts given by the participants showed a real difference. The think aloud method requires participants to verbalize what comes into their mind when they receive the information written in the scenario script. The interviewer sometimes must lure the participant to further explain the statement. One of the participants (#1) directly refer the sore mouth, later determined some differential diagnosis with taking into consideration some of the clinical features of aphthous stomatitis. Participant #3 also determine a possible diagnosis as aphthous stomatitis based on clinical information available. Initially, participant #2 and #4 stated that they could not determine whether a hypothesis or definitive diagnosis, because the information is not yet complete. But after the additionally information revealed, they could determine some hypothesis even some suspected diagnosis. Interestingly one participant #5 determines the possibility of irreversible pulpitis as a hypothesis or diagnosis, with other differential diagnosis as aphthous stomatitis and oral candidiasis. In every case study, the graph which represents their concept map was redrawn by translating it from Bahasa Indonesia to English. The original concept maps prepared by each participant are attached to the Appendix C.

Case study #1: Participant had already predicted the possibility of oral lesion experienced by the patient as clinical problem, further determining the lesion as recurrent aphthous stomatitis. After the addition of some information, then the participant establishes the differential diagnosis as herpes infection and Behcet's disease. During interview, the participant said that the diseases were similar to the patient's complaint in a hypothetical clinical case. A series of statements or answers from participant #1 in solving problems refers to backward (deductive) reasoning model. The concept map made by participant # 1 was referred to the pre-structural level of knowledge (the SOLO taxonomy 1), where learners may have acquired scattered bits of information, but disorganized and unstructured (Figure 1).

Case study #2: Participant #2 merely determined the clinical problem as mouth sore, based on the initial information obtained. In determining the hypothesis or diagnosis, additional relevant clinical data are needed. As the interview progressed, the participant recognizes the possible etiopathogenesis patient's complaint and determined a few possible diagnoses related to the main problem. The pattern of reasoning by first gathering clinical information to build a hypothesis and continues until the diagnosis is established refers to forward (inductive) reasoning model. The concept map built by the participant #2 represent to the multi-structural level of knowledge (the SOLO taxonomy 3). The learner demonstrates a grasp of one clinical fact obtained directly from the scenario, and putting it as a focus of problem and elucidated several oral lesions as consequences (Figure 2).

Case study #3: Participant #3 asked for additional data immediately after knowing the initial information, stating that it was difficult to establish a hypothesis or diagnosis without that information. However, the participant established stomatitis as suspected diagnosis along with similar oral lesions, and tried to find certain clinical information that can help in confirming it. Clinical reasoning pattern applied in this way

similar to elaborated hypothetico-deductive reasoning. The concept map built by participant #3 showed an attempt to correlate the clinical information from history to clinical findings, but they treated separately. This structure of knowledge matched to the uni-structural level of knowledge (the SOLO taxonomy 2) (Figure 3).

Case study #4: Participant #4 said that 'mouth sore' is the main clinical problem that disturbed oral function, but couldn't determine the hypothesis or probable diagnosis because the information is not yet complete. From history of present illness, the participant then stated stomatitis as hypothesis and some new clinical information led to different diagnosis of herpes labialis. The participant recognized anemia from additional information as possible systemic condition responsible for the development patient's complaint. These problem-solving used was forward (inductive) reasoning model. The final hypothesis or diagnosis wasn't favored, but the concept map created reflected the level of knowledge as the relational level (The SOLO taxonomy 4), where the participants can identify anemia as an excerpt from medical history and linked it to the development patient's complaint. Learner with this level of knowledge structure may understand a relation between several aspects and how they might fit together to form a whole clinical picture (Figure 4).

Case study #5: Participant #5 gave another view to the hypothetical clinical case by stating that the main problem was toothache. Further new information was all come out, the participant still stated the possible diagnosis was irreversible pulpitis which hurts when exposed to stimuli such as eating. The differential diagnosis were stomatitis and oral candidiasis, both can cause difficulty in speaking. The participant attempted to compile all clinical information, and determine the possible diagnosis. Participants only focused on the clinical findings of the oral cavity, and did not relate to one another even to the systemic clinical findings. Based on the participant thought when determined diagnoses, a hypothetico-deductive model regarded as clinical reasoning pattern. The diagram made by participant simply does not depict any concept map (Figure 5), since it is closer to the timeline of disease evolution. The way of this participant thinking refers to the multi-structural, whose focus on several relevant facts but treated separately.

G. Discussion

Clinical reasoning is essential in practice-based disciplines, in the way critical thinking be applied in clinical situations^[17]. Clinical reasoning is the clinician's main task in diagnosis and treatment^[25, 60, 61]. Developing clinical reasoning skills is a critical part of a bigger, unified identity that learner will need to bring to clinical experiences in order to participate in caring for patients and work in teams^[60, 61]. Although clinical reasoning is required to clinical practice on a daily basis, it is not directly taught during didactical stage, but is given deliberately through clinical practice^[2,8,62-64]. Previously, dental education emphasized on how to think critically during clinical decision making; what, when and how to determine dental procedure for oral complaint. Therefore, the portion of learning biomedical knowledge during didactic stage is less than clinical procedural or instrumental knowledge^[65-67]. According to Academic Guidelines of Faculty of Dentistry, University of Gadjah Mada, from the total curriculum credits,

approximately twenty percent are dedicated to basic knowledge and the other twenty percent to biomedical knowledge along with behavioral science. All the teaching and learning processes take place in the early stage of didactic educational. Later the teaching and learning process emphasizes on procedural knowledge and practicing to train psychomotor skills ^[68, 69].

The clinical findings in hypothetical clinical cases related to the scope of oral medicine, one of the clinical sciences of dentistry. Previously the course starts from semester 5 to semester 7, but now started on 4th semester in the newly integrated dental curriculum. The initial course topic is Oral Diagnosis, followed by Diagnosis of Oral Disease, Treatment of Oral Disease, and Dental Management of Medically Compromised Patients. All learning materials require good understanding and comprehension of basic science and biomedical knowledge. In addition to routine practicum, to implement 'early clinical exposure', educator apply student-based learning, or specifically refer to case-based learning. Learners in groups are asked to solve clinical problems from hypothetical cases, recap it as a concept map for easy understanding, presented and conduct a discussion. This condition considered as naturalistic experiment of qualitative studies, the commonly research design used for studying clinical reasoning process. Situations where the intervention occurs naturally without planning refers to naturalistic conditions, resembling experimental requirements ^[70].

There were varied responses from participant in this study after they were skimming the initial information from the hypothetical clinical case. Two of them determine several probable hypothesis or diagnosis, and they regarded on applying a hypothetico-deductive pattern of clinical reasoning, and the rest were presented a forward-reasoning pattern. The clinical reasoning is a problem-solving process commonly used by clinicians. The effectiveness and efficiency of applying it determines how well a clinician's knowledge when providing patient care ^[2, 71]. Key elements of clinical diagnostic reasoning consist patient's story, data obtained, accurate presentation of the problem, generation of hypotheses, search and selection of scripts from memory and determination of diagnoses ^[72]. It is assumed that memory function involves the use of abstract cognitive structures ^[44] and knowledge is organized in elaborate memory network ^[46, 73]. According to structural paradigm, medical knowledge is organized and store in memory as mental representation of diseases. At least four distinct models of mental representations have been proposed: prototype, exemplars, semantics networks and illness script. Illness script is particular sets of symptoms or phrases become associated with particular diagnoses. The illness script connected to semantic qualifiers to form problem representation, that activates clinical memory and allows knowledge to become usable for diagnostic reasoning. Semantic qualifiers used to describe clinical cases as descriptors, which is usually paired and used to compare and contrast clinical phenomenon. It associated to certain disease ^[2, 38, 44, 46, 74, 75].

On acquiring expertise in medicine, learners progress through several transitory stages, characterized by distinctively different knowledge structures. The structure of knowledge in learner's memory naturally develops from beginner, intermediate to expert. The learner gains a lot of basic and biomedical knowledge in the early stage of didactic year. These concepts are linked together in a knowledge network,

then gradually, more concepts are added, refined and more formed sophisticated knowledge network, with increasing length of study ^[13, 33, 40]. At every stage, the clinical reasoning process can be characterized by a line of reasoning consisting of a chain of small steps based on detailed biomedical knowledge. Initial development of clinical reasoning process marked by reduced knowledge followed by dispersed, elaborated causal, scheme and script ^[33] (Figure 6).

The chain of steps as presented in Figure 6 resembles the level of knowledge structure assumed by the concept map in the SOLO taxonomy (Table 2). Learner with 'pre-structural level of knowledge' seems to have scattered bits of information obtained but in unorganized structure and less comprehension of knowledge ^[50]. The pre structural level is seem equivalent to the first steps of the development of knowledge structure. At this stage, learner with 'reduced knowledge' presents little knowledge about disease names and their manifestations and shows to guess when solving problem ^[33]. Chan ^[58] describes 'wild guessing' as one of the explanations for pre-structural level of the SOLO Taxonomy. Based on this, it can be assumed that participant #1 applies guessing when determining the hypothesis. This is proved with extended time, more questions and statements of nescience showed by participants during the interview. The participant #1 has an attempt to recalled some textbook-related clinical fact, looking at available clinical data and trying to match the hypothesis or diagnosis that has been established. The clinical reasoning pattern applied is closer to 'deductive or backward-oriented reasoning', because the initial statement is more general in nature and moves towards a specific conclusion. The addition of new information led to a certain diagnosis ^[76, 77]. A similar pattern is also found in study by Nafea ^[55], where deductive or backward reasoning is applied when novice learner solves clinical problem. The backward reasoning pattern is regarded as characteristic of novice learner's reasoning ^[28, 78].

By the end of the first stage of knowledge acquisition, the initial knowledge network built that allows learner directly connect the lines of reasoning between different concepts within network. In this stage, learner will have 'dispersed knowledge', which mean they have less knowledge about disease, such as knowing the name of many diseases, but few manifestations about each disease ^[13, 33]. It is similar with 'the uni-structural level of knowledge', where the learner manifests a correct grasp of one or two relevant pieces of information obtained directly from the problem but lack of appropriate relations to each other (Chan et al., 2002; Bakouli and Jimoyiannis, 2016). The learner at this stage commonly uses hypothetical deductive reasoning when solving problem ^[33]. Participant #3, who showed have these structure and level of knowledge, applies an 'elaborated model of hypothetico-deductive reasoning', which learner reasoned by first generating few hypotheses very early as soon as the first pieces of data became available and then testing a set of hypotheses to account for clinical data. The learner selectively collected data focusing only on the relevant data and applied hypothetico-deductive process in the end ^[79].

With increasing knowledge during skill development, learners would demonstrate 'elaborated causal network' which has rich knowledge about diseases and their manifestations with detailed cause-effect links exist in memory. Furthermore, they can clearly explain the causes and consequences of disease in terms of general underlying pathophysiological process ^[13, 80]. The structure of knowledge level 3 (multi-

structural) SOLO taxonomy can represent end stage of 'dispersed knowledge', while the structure of knowledge level 4 (relational) represents early stage of 'elaborated causal network'. Both of them can show slight connectivity between one or two aspects, even they were still novice. The multi-structural level of knowledge has an incomplete understanding obtained due to focus on several relevant concepts, and seems recognize the relation between them but without further elaboration [58, 81]. Meanwhile, the relational level of knowledge shows an understanding of various concepts and their integration to form a coherent structure [50]. Participant #2 who have multi-structure level and participant #4 who have relational level of knowledge, both applied 'inductive or forward-oriented reasoning' when solved the problem. A forward-oriented reasoning pattern is reasoning strategy from data to hypothesis. The initial information as reflected on chief complaint does not immediately lead to the formation of a hypothesis or diagnosis, but needed more clinical data are required to determine it. Later, one by one the new clinical data obtained leads to the generation of hypotheses, and by adding new clinical data and considering its relevance, the possibility of a diagnosis can be made [28].

Clinical problems solving is not easy task for under-graduate dental students. As health professional, they must have and could demonstrate competence in clinical knowledge and skills. Given the limited previous clinical experience with real patients, dental undergraduate students were naturally concerned with symptoms and signs as it told by patient or written medical record or hypothetical case, later recall and retrieve their knowledge of physical manifestations of diseases from memory [24, 72]. Basically, theoretical conceptual knowledge has been obtained during didactical stage, that take places in the first four-five years. The teaching and learning process is largely based on textbook, hence the resulting perspective on disease is prototypical, with only limited comprehension to the variability disease manifests in reality [28]. Prototype refers to organization of clinical categories in memory around particular exemplars and serve as anchors for other members of the category [46]. On the other hand, clinical procedural knowledge taught is limited to theory and simulation during practicum [33, 82]. This fact can explain that only some characteristics of the knowledge structure from the stages of clinical reasoning development were found in this study, but no 'scheme' and 'script'. Both of this level of knowledge structure develops when learner has increased their expertise, whether they intermediate or expertise. Clinical procedural knowledge along with clinical experience with real patient have a major role in developing expertise [8, 82].

H. Conclusion

It concluded that undergraduate dental student will apply clinical reasoning patterns according to their knowledge gain during didactical stage. They will solve clinical problems by recalling and retrieving knowledge from their memory. Learners with inadequate clinical knowledge will applied backward (hypothesis-driven) reasoning pattern which rely on guessing, meanwhile learners with adequate clinical knowledge will applied forward (data-driven) reasoning pattern when solving problems.

I. Recommendations

The traditionally, clinical environment for preclinical dental education is an apprenticeship model, where learning is frequently focused on procedural knowledge that are discipline-based, then faculty members from each discipline validate whether the learner mastered the steps or not in practical session. Unfortunately, in the end, this process tends to be a mechanical approach to acquire knowledge and skills, and critical decisions. There must be a change in dental education, whether curriculum, teaching and learning methods, instructional methods or dental environment, which emphasize on critical thinking and clinical reasoning in order to provide optimal dental health services.

Declarations

Ethics approval and consent to participate (Ethical approval, Accordance statement, Informed consent to participate statements)

Ethical approval /Institutional Review Board Statement.

The study was conducted according to the guidelines of the Declaration of Helsinki on the ethical principles of research involving human subjects, and approved by the Medical and Health Research Ethics Committee (MHREC), Faculty of Medicine, Public Health, and Nursing University of Gadjah Mada Indonesia (No: KE/FK/1183/EC/2019 on October, 11 2019). The study is carried out after getting approval from the Faculty of Dentistry, University of Gadjah Mada, Yogyakarta Indonesia (No.11709/UN1/FKG.1/Set.KGI/LT/2019). The study was conducted in January 2020.

Author accordance statement.

I, Bernadetta Esti Chrismawaty, declare that I am fully responsible for the paper entitled 'Clinical reasoning pattern used in oral health problem solving – A case study in Indonesian undergraduate dental student', is original, has not published by any journal and is not subjected to another journal. I affirm that all methods, written in study protocol, in accordance with the relevant guidelines and regulations, as evidenced by the Ethics approval and consent to participate. I have reviewed, ensure that all data written are correct and accurate, and the cited information has been included in the references.

Informed consent to participate statements.

Each participant received two forms before the study was conducted, which contained information for the subject and willingness to participate in the study. Both are important to obtain a statement of consent, after obtaining clear, detailed and sufficient information about the research to be carried out. The participant notification sheet (INFORMATION FOR SUBJECT) provides information regarding: a) the aims and objectives of the study, b) the participants who are eligible to become study respondents, c) study procedures and implementation d) risks and benefits of participating in the study, e) confidentiality, f) compensation for participants, g) contacted phone numbers of researchers, h) volunteering in this study. Willingness to participate in the study (SUBJECT'S CONSENT) includes a statement that: a) has received complete information about the aims and objectives of the study, b) has had the opportunity to ask

questions and discuss the study, c) obtain satisfactory answers to all questions, d) receive sufficient information regarding the research procedures and their implications for health and safety, e) free to withdraw from the study, at any time, without giving reasons for withdrawing and most importantly without affecting the future learning, f) consent to the publication of study results, with the assurance that confidentiality will be maintained by the researcher. All participants gave their informed consent for inclusion before they participated in the study.

Consent for publication.

From the subject's consent above, written informed consent has been obtained from the participants to publish this paper.

Availability of data and materials

The data presented in this study are available on request from the corresponding author. Complete written data is not provided for publication due to language barriers (the language used is Bahasa Indonesia, which is the participant's and author's native language). However, the original concept maps drawn by all participants were presented in appendix C, because the graphs are more universal.

Competing interests.

The authors declare that we have no competing interests. There are no financial, commercial, legal, or professional relationship with other organizations, or with the people working with us, that could influence our study.

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Authors' contributions.

- BEC developed the study and managed the design, data collection, analysis, and drafting of the manuscript text and prepared all figures and tables.
- GRR contributed to study design, conducted data collection, screening, analysis, and drafting the manuscript.
- OE and IDA participated in data analysis and drafting of the manuscript.

All authors read, reviewed, and approved the final manuscript.

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References

1. Khatami S, MacEntee MI, Loftus S. Clinical reasoning in dentistry. In: Higgs, Joy; Jones, Mark; Loftus, Stephen; Christensen N, editor. in Clinical reasoning in the health professions. Elsevier (Butterworth Heinemann); 2008. page 257–64.
2. Custers EJFM. Training Clinical Reasoning: Historical and Theoretical Background [Internet]. In: ten Cate, Olle; Custers, Eugène J.F.M.; Durning SJ, editor. Principles and Practice of Case-based Clinical Reasoning Education, Innovation. Cham, Switzerland: Springer Nature; 2018. page 21–33. Available from: http://link.springer.com/10.1007/978-3-319-64828-6_2
3. Rencic J, Trowbridge RL, Fagan M, Szauter K, Durning S. Clinical Reasoning Education at US Medical Schools: Results from a National Survey of Internal Medicine Clerkship Directors. J Gen Intern Med [Internet] 2017;32(11):1242–6. Available from: <http://link.springer.com/10.1007/s11606-017-4159-y>
4. Khatami S, MacEntee MI. Evolution of Clinical Reasoning in Dental Education. J Dent Educ [Internet] 2011;75(3):321–8. Available from: <http://doi.wiley.com/10.1002/j.0022-0337.2011.75.3.tb05045.x>
5. Lamster IB, Myers-Wright N. Oral Health Care in the Future: Expansion of the Scope of Dental Practice to Improve Health. J Dent Educ [Internet] 2017;81(9):eS83–90. Available from: <http://doi.wiley.com/10.21815/JDE.017.038>
6. Khatami S, MacEntee MI, Pratt DD, Collins JB. Clinical reasoning in dentistry: a conceptual framework for dental education. J Dent Educ [Internet] 2012;76(9):1116–28. Available from:

<http://www.ncbi.nlm.nih.gov/pubmed/22942407>

7. Glick M, Carrasco-Labra A. Raison d'être for clinical reasoning. *J Am Dent Assoc* [Internet] 2019;150(12):987–90. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0002817719307366>
8. Elstein AS. Thinking about diagnostic thinking: a 30-year perspective. *Adv Heal Sci Educ* [Internet] 2009;14(S1):7–18. Available from: <http://link.springer.com/10.1007/s10459-009-9184-0>
9. Eva KW. What every teacher needs to know about clinical reasoning. *Med Educ* [Internet] 2005;39(1):98–106. Available from: <http://doi.wiley.com/10.1111/j.1365-2929.2004.01972.x>
10. Simmons B. Clinical reasoning: concept analysis. *J Adv Nurs* [Internet] 2010;66(5):1151–8. Available from: <http://doi.wiley.com/10.1111/j.1365-2648.2010.05262.x>
11. Grace S, Orrock P, Vaughan B, Blaich R, Coutts R. Understanding clinical reasoning in osteopathy: A qualitative research approach. *Chiropr Man Ther* [Internet] 2016;24(1):1–10. Available from: <http://dx.doi.org/10.1186/s12998-016-0087-x>
12. Fonteyn ME, Ritter BJ. Clinical reasoning in nursing. In: Higgs, J; Jones, M. A; Loftus, S and Christensen N, editor. *Clinical Reasoning in the Health Professions*. Elsevier (Butterworth Heinemann); 2008. page 235–43.
13. Boshuizen HP, Schmidt HG. The development of clinical reasoning expertise. In: Higgs, J; Jones, M. A; Loftus, S and Christensen N, editor. *Clinical reasoning in the health professions*. Elsevier (Butterworth Heinemann); 2008. page 113–21.
14. Jäkel F, Schreiber C. Introspection in Problem Solving. *J Probl Solving* [Internet] 2013;6(1):20–34. Available from: <https://docs.lib.purdue.edu/jps/vol6/iss1/4>
15. Durning S, Artino AR, Pangaro L, van der Vleuten CP, Schuwirth L. Context and clinical reasoning: understanding the perspective of the expert's voice. *Med Educ* [Internet] 2011;45(9):927–38. Available from: <http://doi.wiley.com/10.1111/j.1365-2923.2011.04053.x>
16. Schwartz A, Elstein AS. Clinical reasoning in medicine. In: Higgs J, Jones MA, Loftus S, Christensen N, editors. *Clinical Reasoning in the Health Professions*. Elsevier (Butterworth Heinemann); 2008. page 223–34.
17. ten Cate O. Introduction [Internet]. In: ten Cate O, Custers EJ, Durning SJ, editors. *Principles and Practice of Case-based Clinical Reasoning Education - A Method for Preclinical Students*. Cham, Switzerland: Springer Nature; 2018. page 3–19. Available from: http://link.springer.com/10.1007/978-3-319-64828-6_1
18. Higgs J, Jones MA. Clinical decision making and multiple problem spaces. In: higgs, Joy; Jones, Mark A; Loftus, Stephen; Christensen N, editor. *Clinical reasoning in the health professions*. Elsevier (Butterworth Heinemann); 2008. page 3–18.
19. Croskerry P. A Universal Model of Diagnostic Reasoning. *Acad Med* [Internet] 2009;84(8):1022–8. Available from: <http://journals.lww.com/00001888-200908000-00014>
20. Kassirer JP. Teaching Clinical Reasoning: Case-Based and Coached. *Acad Med* [Internet] 2010;85(7):1118–24. Available from: <http://journals.lww.com/00001888-201007000-00011>

21. Patel VL, Groen GJ, Arocha JF. Medical expertise as a function of task difficulty. *Mem Cognit* [Internet] 1990;18(4):394–406. Available from: <http://link.springer.com/10.3758/BF03197128>
22. Durning SJ, Dong T, Artino AR, van der Vleuten C, Holmboe E, Schuwirth L. Dual processing theory and experts' reasoning: exploring thinking on national multiple-choice questions. *Perspect Med Educ* [Internet] 2015;4(4):168–75. Available from: <http://link.springer.com/10.1007/s40037-015-0196-6>
23. McBee E, Ratcliffe T, Schuwirth L, O'Neill D, Meyer H, Madden SJ, et al. Context and clinical reasoning. *Perspect Med Educ* [Internet] 2018;7(4):256–63. Available from: <http://link.springer.com/10.1007/s40037-018-0417-x>
24. Koufidis C, Manninen K, Nieminen J, Wohlin M, Silén C. Grounding judgement in context: A conceptual learning model of clinical reasoning. *Med Educ* [Internet] 2020;54(11):1019–28. Available from: <https://onlinelibrary.wiley.com/doi/10.1111/medu.14222>
25. McBee E, Blum C, Ratcliffe T, Schuwirth L, Polston E, Artino AR, et al. Use of clinical reasoning tasks by medical students. *Diagnosis* [Internet] 2019;6(2):127–35. Available from: <https://www.degruyter.com/document/doi/10.1515/dx-2018-0077/html>
26. Hicks EP, Kluemper GT. Heuristic reasoning and cognitive biases: Are they hindrances to judgments and decision making in orthodontics? *Am J Orthod Dentofac Orthop* [Internet] 2011;139(3):297–304. Available from: <http://dx.doi.org/10.1016/j.ajodo.2010.05.018>
27. Chambers DW, Mirchel R, Lundergan W. An Investigation of Dentists' and Dental Students' Estimates of Diagnostic Probabilities. *J Am Dent Assoc* [Internet] 2010;141(6):656–66. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S0002817714647413>
28. Patel VL, Arocha JF, Zhang J. *Medical Reasoning and Thinking* [Internet]. Oxford University Press; 2012. Available from: [http://acad88.sahs.uth.tmc.edu/research/publications/CHTR_Medicine-Patel final submission.pdf](http://acad88.sahs.uth.tmc.edu/research/publications/CHTR_Medicine-Patel%20final%20submission.pdf)
29. Kaufman DR, Yoskowitz NA, Patel VL. Clinical reasoning and biomedical knowledge: implications for teaching. In: Higgs, Joy; Jones, Mark A; Loftus, Stephen; Christensen N, editor. *Clinical Reasoning in the Health Professions*. Elsevier (Butterworth Heinemann); 2008. page 137–50.
30. Cutrer WB, Sullivan WM, Fleming AE. Educational Strategies for Improving Clinical Reasoning. *Curr Probl Pediatr Adolesc Health Care* [Internet] 2013;43(9):248–57. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S1538544213000941>
31. Paivio A. Dual Coding Theory and Education. In: *Pathways to Literacy Achievement for High Poverty Children*. 2006. page 1–20.
32. Norman G. Research in clinical reasoning: Past history and current trends. *Med Educ* [Internet] 2005;39(4):418–27. Available from: <http://doi.wiley.com/10.1111/j.1365-2929.2005.02127.x>
33. Harasym PH, Tsai T-C, Hemmati P. Current Trends in Developing Medical Students' Critical Thinking Abilities. *Kaohsiung J Med Sci* [Internet] 2008;24(7):341–55. Available from: [http://doi.wiley.com/10.1016/S1607-551X\(08\)70131-1](http://doi.wiley.com/10.1016/S1607-551X(08)70131-1)
34. Pelaccia T, Tardif J, Tribby E, Charlin B. An analysis of clinical reasoning through a recent and comprehensive approach: the dual-process theory. *Med Educ Online* [Internet] 2011;16(1):5890.

Available from: <https://www.tandfonline.com/doi/full/10.3402/meo.v16i0.5890>

35. Eccles DW, Aarsal G. The think aloud method: what is it and how do I use it? *Qual Res Sport Exerc Heal* [Internet] 2017;9(4):514–31. Available from: <http://doi.org/10.1080/2159676X.2017.1331501>
36. Pinnock R, Young L, Spence F, Henning M, Hazell W. Can Think Aloud Be Used to Teach and Assess Clinical Reasoning in Graduate Medical Education? *J Grad Med Educ* [Internet] 2015;7(3):334–7. Available from: <http://www.jgme.org/doi/10.4300/JGME-D-14-00601.1>
37. Bowen JL, Ilgen JS. Now You See It, Now You Don't: What Thinking Aloud Tells Us About Clinical Reasoning. *J Grad Med Educ* [Internet] 2014;6(4):783–5. Available from: <http://www.jgme.org/doi/abs/10.4300/JGME-D-14-00492.1>
38. Koufidis C, Manninen K, Nieminen J, Wohlin M, Silén C. Unravelling the polyphony in clinical reasoning research in medical education. *J Eval Clin Pract* [Internet] 2021;27(2):438–50. Available from: <https://onlinelibrary.wiley.com/doi/10.1111/jep.13432>
39. Kahlke R, Eva K. Constructing critical thinking in health professional education. *Perspect Med Educ* [Internet] 2018;7(3):156–65. Available from: <http://link.springer.com/10.1007/s40037-018-0415-z>
40. Van De Wiel MWJ, Boshuizen HPA, Schmidt HG. Knowledge restructuring in expertise development: Evidence from pathophysiological representations of clinical cases by students and physicians. *Eur J Cogn Psychol* [Internet] 2000;12(3):323–56. Available from: <http://www.tandfonline.com/doi/abs/10.1080/09541440050114543>
41. McLaughlin K, Rikers RM, Schmidt HG. Is analytic information processing a feature of expertise in medicine? *Adv Heal Sci Educ* [Internet] 2008;13(1):123–8. Available from: <http://link.springer.com/10.1007/s10459-007-9080-4>
42. Auclair F. Problem formulation by medical students: an observation study. *BMC Med Educ* [Internet] 2007;7(1):16. Available from: <https://bmcmmededuc.biomedcentral.com/articles/10.1186/1472-6920-7-16>
43. Schmidt HG, Boshuizen HPA. On acquiring expertise in medicine. *Educ Psychol Rev* [Internet] 1993;5(3):205–21. Available from: <http://link.springer.com/10.1007/BF01323044>
44. Charlin B, Boshuizen HPA, Custers EJ, Feltovich PJ. Scripts and clinical reasoning. *Med Educ* [Internet] 2007;41(12):1178–84. Available from: <http://doi.wiley.com/10.1111/j.1365-2923.2007.02924.x>
45. Custers EJFM. Thirty years of illness scripts: Theoretical origins and practical applications. *Med Teach* [Internet] 2015;37(5):457–62. Available from: <http://www.tandfonline.com/doi/full/10.3109/0142159X.2014.956052>
46. Bordage G. Prototypes and semantic qualifiers: from past to present. *Med Educ* [Internet] 2007;41(12):1117–21. Available from: <https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2923.2007.02911.x>
47. Epstein RM. Assessment in Medical Education. *N Engl J Med* [Internet] 2007;356(4):387–96. Available from: <http://www.nejm.org/doi/10.1056/NEJMra054784>

48. Adom D, Adu-Mensah J, Dake DA. Test, measurement, and evaluation: Understanding and use of the concepts in education. *Int J Eval Res Educ* [Internet] 2020;9(1):109. Available from: <http://ijere.iaescore.com/index.php/IJERE/article/view/20457>
49. Bowers N, Brandon M, Hill CD. The Use of a Knowledge Survey as an Indicator of Student Learning in an Introductory Biology Course. *Cell Biol Educ* [Internet] 2005;4(4):311–22. Available from: <https://www.lifescied.org/doi/10.1187/cbe.04-11-0056>
50. Brabrand C, Dahl B. Using the SOLO taxonomy to analyze competence progression of university science curricula. *High Educ* [Internet] 2009;58(4):531–49. Available from: <http://link.springer.com/10.1007/s10734-009-9210-4>
51. Boulton-Lewis GM. The SOLO Taxonomy as a Means of Shaping and Assessing Learning in Higher Education. *High Educ Res Dev* [Internet] 1995;14(2):143–54. Available from: <http://www.tandfonline.com/doi/abs/10.1080/0729436950140201>
52. Boulton-Lewis G. Tertiary students' knowledge of their own learning and a SOLO Taxonomy. *High Educ* [Internet] 1994;28(3):387–402. Available from: <http://link.springer.com/10.1007/BF01383724>
53. Maupomé G, Schrader S, Mannan S, Garetto L, Eggertsson H. Diagnostic thinking and information used in clinical decision-making: a qualitative study of expert and student dental clinicians. *BMC Oral Health* [Internet] 2010;10(1):11. Available from: <https://bmcoralhealth.biomedcentral.com/articles/10.1186/1472-6831-10-11>
54. Behar-Horenstein LS, Schneider-Mitchell G, Graff R. Promoting the Teaching of Critical Thinking Skills Through Faculty Development. *J Dent Educ* 2009;73(6):665–75.
55. Nafea ET, Dennick R. Clinical reasoning skills in final-year dental students: A qualitative cross-curricula comparison. *Eur J Dent Educ* [Internet] 2018;22(2):101–8. Available from: <https://onlinelibrary.wiley.com/doi/10.1111/eje.12256>
56. Coderre S, Mandin H, Harasym PH, Fick GH. Diagnostic reasoning strategies and diagnostic success. *Med Educ* [Internet] 2003;37(8):695–703. Available from: <http://doi.wiley.com/10.1046/j.1365-2923.2003.01577.x>
57. Kinchin IM. Concept Mapping as a Learning Tool in Higher Education: A Critical Analysis of Recent Reviews. *J Contin High Educ* [Internet] 2014;62(1):39–49. Available from: <http://www.tandfonline.com/doi/abs/10.1080/07377363.2014.872011>
58. Chan CC, Tsui MS, Chan MYC, Hong JH. Applying the Structure of the Observed Learning Outcomes (SOLO) Taxonomy on Student's Learning Outcomes: An empirical study. *Assess Eval High Educ* [Internet] 2002;27(6):511–27. Available from: <http://www.tandfonline.com/doi/abs/10.1080/0260293022000020282>
59. Baxter P, Jack S. Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *Qual Rep* [Internet] 2015;13(4):544–59. Available from: <https://nsuworks.nova.edu/tqr/vol13/iss4/2/>
60. Goldszmidt M, Minda JP, Bordage G. Developing a Unified List of Physicians' Reasoning Tasks During Clinical Encounters. *Acad Med* [Internet] 2013;88(3):390–4. Available from:

61. McBee E, Ratcliffe T, Goldszmidt M, Schuwirth L, Picho K, Artino AR, et al. Clinical reasoning tasks and resident physicians: What do they reason about? *Acad Med* 2016;91(7):1022–8.
62. Artino AR, Cleary TJ, Dong T, Hemmer PA, Durning SJ. Exploring clinical reasoning in novices: a self-regulated learning microanalytic assessment approach. *Med Educ* [Internet] 2014;48(3):280–91. Available from: <http://doi.wiley.com/10.1111/medu.12303>
63. Pinnock R, Welch P. Learning clinical reasoning. *J Paediatr Child Health* [Internet] 2014;50(4):253–7. Available from: <http://doi.wiley.com/10.1111/jpc.12455>
64. Persky AM, Robinson JD. Moving from Novice to Expertise and Its Implications for Instruction. *Am J Pharm Educ* [Internet] 2017;81(9):6065. Available from: <http://www.ajpe.org/lookup/doi/10.5688/ajpe6065>
65. Scully C, Miller CS, Aguirre Urizar JM, Alajbeg I, Almeida OPD, Bagan JV, et al. Oral medicine (stomatology) across the globe: Birth, growth, and future. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2016;121(2):149-157.e5.
66. Whipp J, Ferguson D, Wells L, Iacopino A. Rethinking knowledge and pedagogy in dental education. *J Dent Educ* [Internet] 2000;64(12):860–6. Available from: <https://onlinelibrary.wiley.com/doi/10.1002/j.0022-0337.2000.64.12.tb03387.x>
67. Scott J. Dental Education in Europe: The Challenges of Variety. *J Dent Educ* [Internet] 2003;67(1):69–78. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/12540108>
68. Howard KM, Stewart T, Woodall W, Kingsley K, Ditmyer M. An integrated curriculum: evolution, evaluation, and future direction. *J Dent Educ* [Internet] 2009;73(8):962–71. Available from: <https://onlinelibrary.wiley.com/doi/10.1002/j.0022-0337.2009.73.8.tb04785.x>
69. Pyle MA. New Models of Dental Education and Curricular Change: Their Potential Impact on Dental Education. *J Dent Educ* 2012;1(January):89–97.
70. Gruppen LD, Frohna AZ. Clinical Reasoning. In: Leithwood K, Chapman J, Corson D, Hallinger P, Hart A, editors. *International Handbook of Research*. Dordrecht: Kluwer International Handbooks of Education; 2002. page 205.
71. Kiesewetter J, Ebersbach R, Görlitz A, Holzer M, Fischer MR, Schmidmaier R. Cognitive problem solving patterns of medical students correlate with success in diagnostic case solutions. *PLoS One* [Internet] 2013;8(8):e71486. Available from: <https://dx.plos.org/10.1371/journal.pone.0071486>
72. Bowen JL. Educational Strategies to Promote Clinical Diagnostic Reasoning. *N Engl J Med* [Internet] 2006;355(21):2217–25. Available from: [http://references.tomhsiong.com/Differential Diagnosis/Educational Strategies to Promote Clinical Diagnostic Reasoning.pdf](http://references.tomhsiong.com/Differential%20Diagnosis/Educational%20Strategies%20to%20Promote%20Clinical%20Diagnostic%20Reasoning.pdf)
73. Woods NN, Brooks LR, Norman GR. It all make sense: biomedical knowledge, causal connections and memory in the novice diagnostician. *Adv Heal Sci Educ* [Internet] 2007;12(4):405–15. Available from: <http://link.springer.com/10.1007/s10459-006-9055-x>
74. Durning S, Artino AR, Pangaro L, van der Vleuten CP, Schuwirth L. Context and clinical reasoning: Understanding the perspective of the expert's voice. *Med Educ* 2011;45(9):927–38.

75. Charlin B, Tardif J, Boshuizen HPA. Scripts and Medical Diagnostic Knowledge. *Acad Med* [Internet] 2000;75(2):182–90. Available from: <http://journals.lww.com/00001888-200002000-00020>
76. Barrows HS, Feltovich PJ. The clinical reasoning process. *Med Educ* [Internet] 1987;21(2):86–91. Available from: <https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2923.1987.tb00671.x>
77. Arocha JF, Patel VL. Novice Diagnostic Reasoning in Medicine: Accounting for Evidence. *J Learn Sci* 1995;4(4):355–84.
78. Monteiro SM, Norman G. Diagnostic Reasoning: Where We've Been, Where We're Going. *Teach Learn Med* [Internet] 2013;25(sup1):S26–32. Available from: <http://www.tandfonline.com/doi/abs/10.1080/10401334.2013.842911>
79. Arocha JF, Wang D, Patel VL. Identifying reasoning strategies in medical decision making: A methodological guide. *J Biomed Inform* [Internet] 2005;38(2):154–71. Available from: <https://linkinghub.elsevier.com/retrieve/pii/S1532046405000146>
80. De Bruin AB, Schmidt HG, Rikers RM. The role of basic science knowledge and clinical knowledge in diagnostic reasoning: A structural equation modeling approach. *Acad Med* 2005;80(8):765–73.
81. Bakouli V, Jimoyiannis A. Concept mapping as cognitive tool in science education: An analysis of students' learning using SOLO taxonomy [Internet]. In: Smyrniou Z, Riopel M, Sotiriu M, editors. *Recent Advances in Science and Technology Education, Ranging from Modern Pedagogies to Neuroeducation and Assessment*. Cambridge Scholars Publishing; 2016. page 43–58. Available from: <https://www.researchgate.net/publication/327252136%0AConcept>
82. Schmidmaier R, Eiber S, Ebersbach R, Schiller M, Hege I, Holzer M, et al. Learning the facts in medical school is not enough: which factors predict successful application of procedural knowledge in a laboratory setting? *BMC Med Educ* [Internet] 2013;13(1):28. Available from: <https://bmcmmededuc.biomedcentral.com/articles/10.1186/1472-6920-13-28>
83. Coleman GC, Flaitz CM, Vincent SD. Differential diagnosis of oral soft tissue lesions. *Tex Dent J* [Internet] 2002;119(6):484–8, 490–2, 494–503. Available from: <http://www.ncbi.nlm.nih.gov/pubmed/12141128>

Tables

Table 1. A predetermined content analysis, with theory or relevant research findings as guidance for initial codes of clinical reasoning pattern used in this study ^[1,16,34,54–56].

Hypothetico-deductive reasoning	Participants are stated to apply HD reasoning if the limited number of presumptive clinical diagnoses or hypotheses were generated during the initial presentation of data, and using them to direct further inquiry.
Forward (inductive) reasoning	Participant is stated to apply forward (inductive) reasoning if they first make a series of specific observations and interpretations of clinical data, determines several suspected diagnoses or hypotheses, and refines it until a diagnostic solution is reached.
Backward (deductive) reasoning	Participants are stated to apply backward (deductive) reasoning if they formed multiple, sometimes conflicting hypotheses quickly, and then reinterpret the data or acquire new clarified data to test the hypothesis.
Forward and backward reasoning	Participants are stated to apply forward and backward reasoning if they first observe and interpret clinical data, establish several hypotheses, and to refine them, the participants reinterpret the data or obtain new data that is clarified to test the hypothesis.
Pattern recognition	Participants are stated to apply pattern recognition when determining hypotheses or diagnoses by matching them with information automatically and directly from a well-structured knowledge base.

Table 2. The levels and description of the SOLO taxonomy ^[50,51,58] with suggested concept maps (<https://pamhook.com/free-resources/downloadable-resources/>)

SOLO Taxonomy	Description (Structure of knowledge)	Suggested map concept
SOLO 1: the pre-structural level	The learner does not have a proper understanding of the knowledge or use irrelevant information and / or miss key information.	
SOLO 2: the uni-structural level	The learner demonstrates a correct grasp of one aspect, fact or idea obtained directly from the problem and the task to be implemented.	
SOLO 3: the multi-structural level	The learner has an incomplete understanding obtained by focusing on several relevant aspects, facts or concepts.	
SOLO 4: the relational level	The learner may understand relations between several aspects and how they might fit together to form a whole. The learner responses are more robust; they make sense of the various aspects of the topic and integrate the parts into a coherent structure.	
SOLO 5: The extended abstract level	The learner may generalize structure beyond the particular problem to be solved, and links the problem to a broader context. The learner may perceive structure from many different perspectives, and transfer ideas to new areas.	

Figures

Figure 1

The concept map made by participant #1 shows the pre-structural level of knowledge (the SOLO taxonomy 1). (The illustrations depict from <https://pamhook.com/free-resources/downloadable-resources/>).

Figure 2

The concept map made by participant #2 showed the multi-structural level of knowledge (the SOLO taxonomy 3). (The illustrations depict from <https://pamhook.com/free-resources/downloadable-resources/>).

Figure 3

The concept map made by participant #3 showed the uni-structural level of knowledge (the SOLO taxonomy 2). (The illustrations depict from <https://pamhook.com/free-resources/downloadable-resources/>).

Figure 4

The concept map made by participant #4 showed the relational level of knowledge (the SOLO taxonomy 4). (The illustrations depict from <https://pamhook.com/free-resources/downloadable-resources/>).

Figure 5

The concept map made by participant #5 supposed to be the time line of patient illnesses, but the way of this participant thinking could categorize as the multi-structural knowledge (the SOLO taxonomy 3) (The illustrations depict from <https://pamhook.com/free-resources/downloadable-resources/>).

Figure 6

The development of knowledge structure from novice, intermediate to expert ^[33].

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [AppendixA.Thehypotheticalclinicalcaseasatriggerforclinicalproblemsolving.docx](#)
- [AppendixB.Theinterpretationofhypotheticalclinicalcase..docx](#)
- [AppendixC.Theoriginalgraphrepresentsheclinicalconceptmapdrawnbyeachparticipant..docx](#)