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Cover Page Footnote

This article comprises part of a manuscript-style dissertation the first author submitted to the University of Georgia.

The Interdisciplinary Journal of Problem-based Learning

SPECIAL ISSUE ON COMPETENCY ORIENTATION IN PROBLEM-BASED LEARNING

The Role of Argumentation in Hypothetico-Deductive Reasoning During Problem-Based Learning in Medical Education: A Conceptual Framework

Hyunjung Ju (Inje University College of Medicine) and Ikseon Choi (The University of Georgia)

Abstract

One of the important goals of problem-based learning (PBL) in medical education is to enhance medical students' clinical reasoning—hypothetico-deductive reasoning (HDR) in particular—through small group discussions. However, few studies have focused on explicit strategies for promoting students' HDR during group discussions in PBL. This paper proposes a novel conceptual framework that integrates Toulmin's argumentation model (1958) into Barrows's HDR process (1994). This framework explains the structure of argumentation (a claim, data, and a warrant) contextualized in each phase of HDR during PBL. This paper suggests four instructional strategies—understanding argument structures, questioning, elaborating on structural knowledge, and assessing argumentation—for promoting medical students' argumentation in relation to HDR processes. Further implications of the proposed framework for other disciplines, such as science, legal, and engineering education, are also discussed.

Keywords: argumentation, hypothetico-deductive reasoning (HDR), problem-based learning (PBL)

Introduction

Problem-based learning (PBL) is a method of learning in which the learners first encounter a problem and then continue with the student-centered inquiry process of understanding and solving the problem (Barrows & Tamblyn, 1980; Schwartz, Mennin, & Webb, 2001). The PBL method expects students to acquire basic concepts of a discipline in the context of problems, which can support the retrieval and application of this knowledge later in their professional practice, and to develop students' reasoning and problem-solving skills (Barrows & Tamblyn, 1980; Savery, 2006).

One of the essential elements of PBL is group discussion: students in small groups of four to eight are encouraged to construct and exchange their ideas and challenge others' thoughts, beliefs, and perceptions (Hmelo-Silver & Barrows, 2008). Through small group discussions, students explore causes of a given problem that is complex and ill structured, generate multiple solutions, negotiate alternative solutions to the problem, and build an essential body of knowledge (Hmelo-Silver, 2004; Johnson, Johnson, & Smith, 2007). During these group discussions, the students should be able to construct valid arguments, providing justifications for their ideas in order to rationally resolve the problem and make reasoned decisions (Jonassen, 2011). In other words, argumentation is one of the key mechanisms for mediating evidence-based communications among students in their small group problem solving (Jonassen, 2011; Kuhn, 1992; Walton, 2007).

A pedagogical emphasis on argumentation is consistent with general educational goals that seek to enhance students' reasoning abilities, including paying attention to reasons, evaluating the quality and relevance of those reasons, and formulating valid ideas or beliefs based on those reasons (Siegel, 1995). This suggests that supporting students' argumentation involves promoting their reasoning and problem solving in PBL (Cerbin, 1988; Jonassen, 2011). Several studies have explored instructional strategies for fostering students'

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argumentation skills for ill-structured problem solving, such as using computer-supported collaborative argumentation software (e.g., Cho & Jonassen, 2002) or questioning (e.g., McNeill & Pimentel, 2010). In addition to developing argumentation promotion strategies, it would be essential to identify what reasoning strategies or problem-solving processes are applied in a specific discipline of PBL, such as medical education, and then to determine what primary content should be included in arguments within each phase of problem solving in PBL. This can guide the construction of a framework for the structure of argumentation in the specific discipline of PBL, which will provide students with guidance as to how to generate sound arguments in terms of each problem-solving process. As the generic structure of argumentation, Toulmin's (1958) argumentation model that specifies primary components of argumentation, such as a claim, data, and a warrant, as well as the mechanisms for generating arguments, has been mostly employed to facilitate argumentation for problem solving in many disciplines, including science education (e.g., Chin & Osborne, 2010). However, research focusing on a unique framework or model integrating argumentation theory and domain-specific reasoning or problem-solving processes is especially scarce.

PBL has been implemented in a variety of professional disciplines, including medical, legal, and engineering education (Savery, 2006; Jonassen, 2011). Since PBL was initially introduced in medical education in the late 1960s, many medical schools around the world have adopted the PBL approach as part of their curricula (Khoo, 2003; Neville, 2009; Savery, 2006). This paper will focus on PBL in a medical education context.

PBL in medical schools helps students develop their clinical reasoning skills, especially hypothetico-deductive reasoning (HDR) skills, that involve the ability to explore causes of a patient's problem and make decisions about the management of the problem, applying basic science and clinical knowledge (Barrows, 1985, 1994; Barrows & Tamblyn, 1980). In the HDR process, students in a small group are first presented with a patient's medical problem through a paper, video, or standardized patient before any study occurs in the area of the problem, and they generate multiple hypotheses to explain the causes of the patient's problem, conduct inquiries to test their hypotheses, and finally make a diagnostic decision and treatment plan for the patient (Barrows, 1985, 1994; Barrows & Tamblyn, 1980). Thus, HDR is considered as a clinical reasoning model as well as a learning model (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Groves, 2007; Hmelo, 1998; Patel, Arocha, & Zhang, 2005). Although PBL is expected to promote students' clinical reasoning skills, especially HDR skills, in theory when compared to traditional methods, there have been gaps between theoretical outcomes and those actually obtained in practice (Hung, 2011). Patel and her colleagues (1993) reported that when explaining clinical cases, students in PBL curricula generated more extensive elaborations of biomedical information than students in the non-PBL curriculum did, but their elaborations were less coherent and sometimes resulted in the generation of diagnostic reasoning errors. Ju et al. (2016) also found that medical students had difficulties engaging in systemic clinical reasoning processes during PBL (e.g., jumping to a specific diagnosis for a patient's problem). As HDR plays a key role in learning and problem solving in PBL, it is necessary to explore ways to empower students' HDR in PBL. Considering that argumentation ability is related to reasoning ability, as discussed earlier, students should be encouraged to engage in argumentation so that they can integrate basic scientific knowledge into clinical contexts, take a coherent approach to diagnostic inquiry, and build a collective model of a patient's illness during HDR processes (Frederiksen, 1999; Hmelo-Silver & Barrows, 2008). In order for medical students to generate reasoned arguments during PBL, it is important to help them understand the role of argumentation in the HDR process and learn how to structure arguments according to each phase of HDR. Also central to the development of medical students' argumentation skills is scaffolding (Andriessen, 2006; Belland, Glazewski, & Richardson, 2011; Cho & Jonassen, 2002), defined as the process by which more knowledgeable persons (Wood, Bruner, & Ross, 1976) or instructional tools and resources (Puntambekar & Hübscher, 2005) help learners accomplish a task that would otherwise be beyond the learners' abilities. However, there has been little research on specific scaffolding strategies to support medical students' construction of sound arguments with regard to the process of HDR in PBL.

Thus, the purposes of this paper are to develop a conceptual framework for explaining the structure of argumentation contextualized in HDR processes during PBL in a medical education context and to provide possible scaffolding for enhancing students' argumentation in the HDR process. For these purposes, this paper will discuss the nature of HDR and the role of HDR in PBL in terms of medical education as well as the nature of argumentation. Finally, we will propose a conceptual framework that integrates argumentation into the HDR process in a medical education context and discuss instructional recommendations for the proposed framework, including scaffolding arranged by tutors and tools. Although this paper focuses on students' argumentation during PBL used in the medical education field, the conceptual framework will shed light on constructing the structure of argumentation in relation to the problem solving or reasoning process in other disciplines.

Hypothetico-Deductive Reasoning (HDR)

Reasoning involves the process of providing relevant explanations for observational data through a series of logical steps to solve a given problem and make a decision (Feinstein, 1973a). Hypothetico-deductive reasoning is a scientific reasoning approach widely used in the field of science (Lawson, 2000; Patel et al., 2005). Hypothetico-deductive reasoning (HDR) is defined as "relating to, being, or making use of the method of proposing hypotheses and testing their acceptability or falsity by determining whether their logical consequences are consistent with observed data" (University of Florida, 2012). Medical reasoning as hypothetico-deductive is characterized as the embodied scientific method (Barrows & Tamblyn, 1980; Patel, Evans, & Groen, 1989). In medicine, HDR is used to "evaluate and manage a patient's medical problems" (Barrows & Tamblyn, 1980, p. 19) when physicians encounter unfamiliar patient cases (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Sefton, Gordon, & Field, 2008). Physicians' hypothetico-deductive reasoning may incorporate the following phases (Barrows, 1985, 1994; Barrows & Tamblyn, 1980):

(1) Problem framing. When physicians encounter a patient as an unknown with insufficient information, they listen to the patient's initial complaint and perceive a variety of cues (e.g., appearance, age, or personal circumstances) taken from their observations or the patient's remarks and responses to the physicians' own questions. They form an initial concept of a patient's problem as a synthesis of the identified initial cues.

(2) Hypothesis generation. Based on the identified cues, the physicians generate as many hypotheses as possible to explain the patient's problem, using brainstorming and divergent thinking. These hypotheses can be specific diagnostic entities, pathophysiological processes, anatomical locations, or biochemical derangements. When generating and ranking hypotheses, they consider the prevalence of disease and the acuity of the patient's condition (Kovacs & Croskerry, 1999). Hypotheses may be modified, the ranking of hypotheses can be changed, or new hypotheses may be created as the inquiry continues.

(3) Inquiry strategy. The physicians carry out an inquiry to obtain more information that will strengthen, refine, or rule out hypotheses through history taking, physical examinations, or laboratory tests. For the inquiry, they need to employ clinical skills, such as communication skills and technical or psychomotor skills.

(4) Data analysis and synthesis. After obtaining data from the inquiry strategy, they analyze the data against the hypotheses entertained in order to determine whether the data strengthens or weakens any of the hypotheses being considered or suggests new and unsuspected hypotheses, in terms of basic mechanisms responsible for all symptoms, signs, or laboratory findings. Any significant data obtained is added to the information the physicians are accumulating in their minds about the patient's problem. This refers to the ongoing summary of the patient's problem.

(5) Diagnostic decisions. The physicians evaluate each hypothesis for consistency with the obtained data and eliminate competing hypotheses. Upon the conclusion that no more helpful data can be collected from the present encounter, they come to the most likely clinical diagnosis/es as to the underlying mechanisms or pathophysiology involved in the patient's problem.

(6) Therapeutic decisions. They can make appropriate management plans (e.g., surgery or medication) to improve the patient's condition or make a decision on further inquiry (e.g., laboratory or radiology tests) to verify or amplify the correct underlying mechanisms.

Although HDR has several phases, the process is rather iterative (see Figure 1). Some phases of HDR (hypothesis generation, inquiry strategy, and data analysis/synthesis) repeat until physicians decide that they have obtained all the data they need and that one of multiple hypotheses is significantly more likely than the others (Barrows, 1985, 1994; Barrows & Tamblyn, 1980).

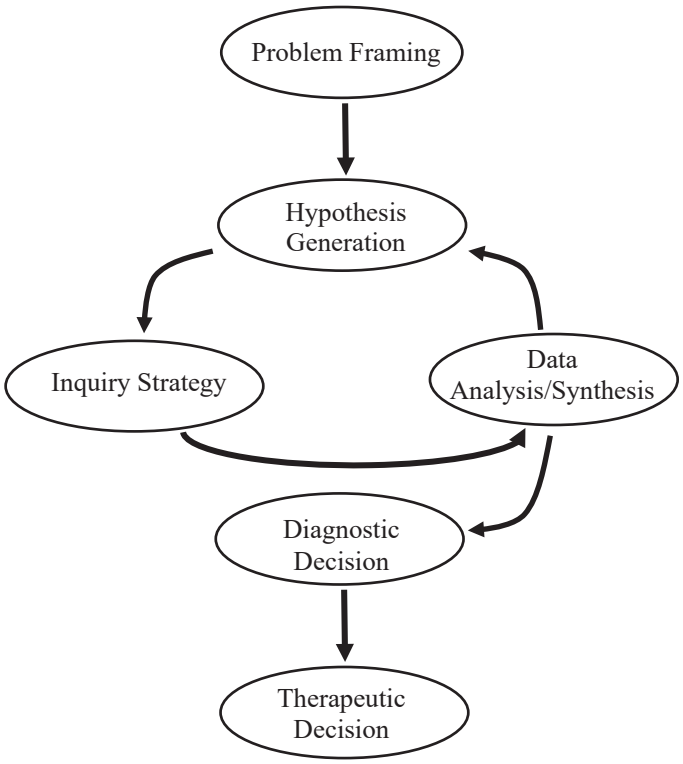

Figure 1. The hypothetico-deductive reasoning process. Adapted from Barrows, 1994.

The HDR process can often be used when domain knowledge and experience are insufficient or when there is uncertainty about a problem's solution (Patel et al., 2005). For example, physicians may employ pattern recognition when encountering a new patient who has similar clinical presentations to patients seen previously, whereas they may resort to HDR when confronted with more complex and unknown patient cases. The HDR model can provide medical students with a useful procedural guideline to solve a diagnostic problem, because most clinical situations do not seem to be familiar to them and they lack experience with routine methods of problem solving (Elstein, 1995). The HDR model as an appropriate approach for helping medical students develop their problem-solving skills is incorporated in PBL (Groves, 2007; Hmelo, 1998; Patel et al., 2005).

Hypothetico-Deductive Reasoning (HDR) in PBL

PBL provides students with opportunities to apply basic concepts, theories, or principles to a given problem context in order to construct reasonable explanations underlying the problem and generate viable solutions to the problem, which can assist in restructuring their existing knowledge base and building new knowledge (Hmelo-Silver, 2004; Savery, 2006). For PBL in medical education, medical students are encouraged to acquire basic scientific knowledge in the context of specific cases posed as clinical problems so they can better retain, apply, and retrieve the knowledge in their future clinical practices; PBL is supposed to develop medical students' abilities to integrate biomedical and clinical knowledge in a way that students' reasoning links clinical information to scientific principles and theories (Barrows, 1994; Barrows & Tamblyn, 1980; Prince, van de Wiel, Scherpbier, van der Vleuten, & Boshuizen, 2000). Clinical knowledge is defined as the knowledge of the attributes of diseases, which relates to its symptoms, signs, treatments, and managements (Diemers, van de Wiel, Scherpbier, Heineman, & Dolmans, 2011; van de Wiel, Boshuizen, & Schmidt, 2000). In contrast, biomedical knowledge includes the knowledge of anatomical, biochemical, pathological, and physiological principles or mechanisms involved in the representations of diseases (Boshuizen & Schmidt, 1992; Diemers et al., 2011; Patel et al., 1989). For students who have little or no clinical experience, biomedical knowledge would be mainly activated in comprehending a patient's problem (van de Wiel et al., 2000). For medical experts, they predominantly use clinical knowledge accumulated from their clinical experiences, rather than biomedical knowledge, to represent and diagnose a patient's problem (Patel et al., 1989), but when faced with an unfamiliar patient's case, they employ their biomedical knowledge for connecting clinical features that are not easily explained (van de Wiel et al., 2000; Woods, Brooks, & Norman, 2007).

In the process of HDR, "the basic science rules (physiological) have to be converted into intermediate rules (pathophysiological) and then into clinical rules (patient-oriented)" (Patel, Groen, & Scott, 1988, p. 402). Basic scientific explanations help students understand why a particular sign or symptom occurs in a specific disease (Feinstein, 1973b; Woods et al., 2007) as well as play a role in controlling the proliferation of hypotheses in clinical reasoning (Feinstein, 1973b; Szolovits, Patil, & Schwartz, 1988). The pathophysiological knowledge about physiological processes or mechanisms of diseases should be mechanistically organized into multiple hierarchies (Szolovits et al., 1988), which can assist students in creating a coherent mental representation of a clinical case when the clinical features become disorganized (Boshuizen & Schmidt, 1992; Woods et al., 2007). Causal, pathophysiological mechanisms of a patient's problem are beneficial in explaining and validating hypotheses responsible for the patient's problem (Miller & Geissbuler, 2007). While engaging in HDR processes, students should be encouraged to analyze the patient's problem, using and retrieving basic science knowledge and focusing on the underlying responsible mechanisms (Barrows, 1985, 1994). In other words, they should be able to understand the normal structure and function of the systems involved as well as pathophysiological mechanisms of the patient's problem at the appropriate level, such as organ, tissue, cellular, or molecular levels (Barrows, 1994).

However, several studies have reported that medical students struggle to transfer biomedical knowledge to clinical cases (Boshuizen & Schmidt, 1992; Diemers et al., 2011; Prince et al., 2000). Students' difficulties in transferring their learning into problem solving can be attributed to diverse factors, such as their incomprehension of underlying concepts (simply memorizing definitions of concepts and theories), lack of reasoning skills, or previous experiences (Dixon & Brown, 2012; Jonassen, 2011). In Patel et al.'s (1988) study, eight first-year and eight second-year medical students were asked to read three basic science texts, followed by a clinical case, then make a diagnosis, and explain the underlying pathophysiological processes of the case. The first-year students tended to apply basic science information to the given clinical problem based on the superficial similarity of the information in the two domains—for example, students related the patient's *abnormal* temperature to *abnormal* body thermoregulation, because *normal* temperature is associated with *normal* body thermoregulation—and they constructed pathophysiological explanations based on their personal experiences. The second-year students used extensive basic science knowledge to explain the pathophysiology of the clinical case, but their causal explanations sometimes seemed incorrect and inconsistent. This indicates that instructional strategies may be needed so that students can build a causal,

scientific explanation of a patient's case that integrates the relevant information learned to clarify the pathophysiological processes involved in the patient's case during HDR processes. Concept mapping has been used as one of the strategies to facilitate students' scientific connections between basic science concepts and clinical contexts (e.g., Rendas, Fonseca, & Pinto, 2006; see the instructional recommendation section for more detail). More importantly, the HDR process, including the coordination of scientific concepts and problems or data to advance an explanation of a patient's problem, entails a series of propositions and inferences within a discourse of reasoned arguments (Duschl & Osborne, 2002). During HDR processes, engaging medical students in explicitly presenting their claims based on reasons can support not only the application of basic science knowledge to a patient's case but also scientific inquiry processes and coherent explanations of the patient's case. This involves argumentation that will be discussed in the following section.

Argumentation

Argumentation refers to a social process in which two or more individuals engage in a dialogue where they construct, exchange, and evaluate claims and provide justifications for the claims (Blair, 2011; Cho & Jonassen, 2002; Jonassen, 2011; Nussbaum, 2011; Walton, 2007). Argumentation is associated with reasoning that plays a key role in problem solving or decision making (Cerbin, 1988; Jiménez-Aleixandre & Rodriguez, 2000; Jonassen, 2011; Kuhn, 1992; van Eemeren et al., 1996). In PBL, students should be encouraged to construct valid arguments about how they investigated a problem, what caused the problem, and what solutions are necessary for quality problem solving. Also, determining students' argumentation ability can provide a means for assessing their problem-solving or reasoning abilities (Jonassen, 2011; Nussbaum, 2011).

Argumentation theory can provide a theoretical framework not only for understanding collaborative problem solving from both social and cognitive perspectives (Anderson et al., 2001; Driver, Newton, & Osborne, 2000) but also for developing tools to analyze and evaluate students' thinking and reasoning (Driver et al., 2000; Jonassen, 2011; Nussbaum, 2011; Siegel, 1995). Toulmin's model (1958) has been considered to be seminal in the field of argumentation theory (Andrews, 2005; Jiménez-Aleixandre & Rodriguez, 2000; Jonassen, 2011; Nussbaum, 2011). Toulmin's model (1958) describes the constitutive elements of an argument and represents the functional relationships among them (see Figure 2). Toulmin (1958) identified three essential components which contribute to an argument: (1) a claim: an assertion or conclusion whose merits need to be established; (2) data: facts to provide support for the claim; and (3) a warrant: a reason that justifies the transition from the data to the claim and reveals the relevance of the data for the claim (e.g., rules, principles, or a rule of inference). Central to the soundness of arguments is data that supports claims and warrants that act as inferential

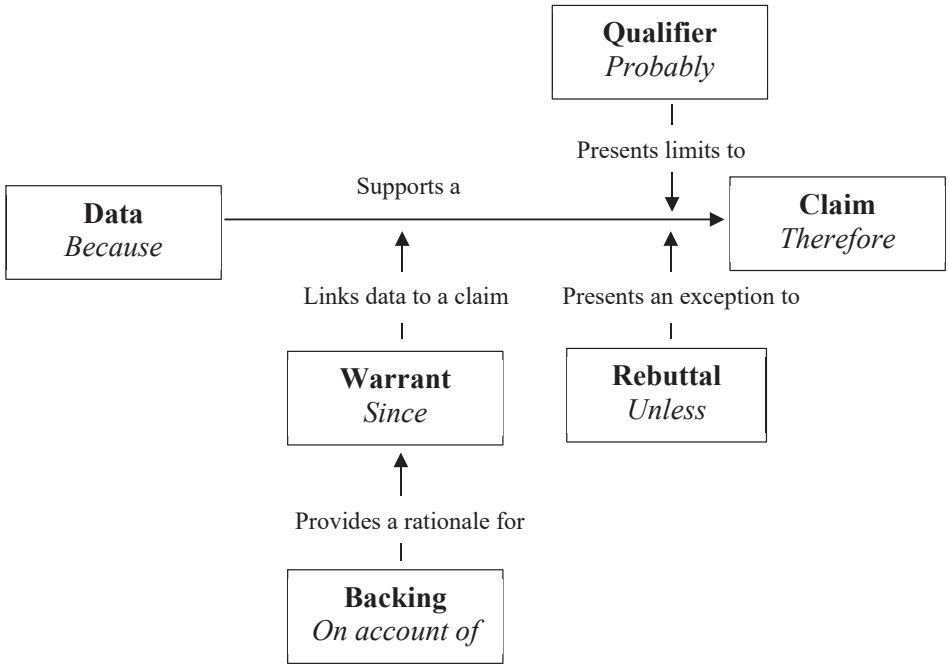

Figure 2. The structure of an argument. Adapted from Toulmin, 1958.

bridges between data and claims; without data and warrants, it would become impossible for claims or conclusions to be appropriate and legitimate ones (Toulmin, 1958). Furthermore, Toulmin (1958) identified three additional components in more complex arguments: (1) a backing: a basic assumption that provides a rationale for the warrants (e.g., factual information, a principle, value or belief); (2) a rebuttal: a statement that weakens or invalidates the claim; and (3) a qualifier that limits certainty of the claim, which usually includes a modal adverb, such as "most," "perhaps" or "probably." All arguments do not necessarily contain these components; some argument components may be absent or left implicit (Nussbaum, 2011; Toulmin, 1958). Toulmin's model (1958) has been used to determine the structure of arguments and to provide a framework for evaluating the quality of argumentation (Andrews, 2005; Duschl & Osborne, 2002; Newton, Driver, & Osborne, 1999; Nussbaum, 2011). Also, teaching this model can help students learn how an argument should unfold in discussion and make more explicit their justifications (Hewson & Ogunniyi, 2010; Newton et al., 1999; Nussbaum, 2011).

Several studies (e.g., Berland & Reiser, 2009) have found that students have difficulty constructing sound arguments; for example, students provide little evidence to support their claims and give little or no consideration to counterarguments or conflicting evidence (Cerbin, 1988; Driver et al., 2000; Reznitskaya, Anderson, & Kuo, 2007) or students have challenges in articulating warrants or backings to justify their claims and evidence (Jiménez-Aleixandre & Rodriguez, 2000; McNeill, Lizotte, Krajcik, & Marx, 2006). Students' challenges with argumentation can be attributed to students' naïve conceptions of argument structures (Cerbin, 1988; Zeidler, 1997), their lack of knowledge about the issue or topic (Cerbin, 1988; McNeill et al., 2006; von Aufschnaiter, Erduran, Osborne, & Simon, 2008), or teachers' lack of skills in supporting students' argumentation in the classroom (Driver et al., 2000; Newton et al., 1999). It is necessary to develop strategies to overcome the students' difficulties and foster their argumentation.

A Conceptual Framework to Integrate Argumentation into the HDR Process

Based on the previous discussion on HDR and argumentation, this section will elaborate on a framework that explains how the generic structure of argumentation can be contextualized in each phase of HDR in the medical field.

Within the context of HDR processes, it is important for medical students to engage in argumentation, including relating evidence for their claims and reasoning from the claims and evidence by integrating biomedical and clinical knowledge. The students' argumentation will help build scientific, causal explanations for a patient's problem and improve the quality of their scientific inquiry for problem solving about a patient's condition. In order for the students to construct sound arguments during HDR processes, it is essential to provide at least three basic components of Toulmin's (1958) argumentation model in their arguments: a claim, data (evidence), and a warrant. The claim can be a statement that answers the original question or problem. The data that supports students' claims can come from several sources, such as observations, reading materials given to students, or investigations, including interviews, physical examinations, or diagnostic tests. The warrant used to articulate the logic behind why the data support the claim can include pathological and physiological principles, mechanisms, or processes underlying clinical features. For example, when provided with a patient's problem, students can construct an argument, including a claim, data, and a warrant, to generate a hypothesis responsible for the patient's problem as illustrated in Figure 3.

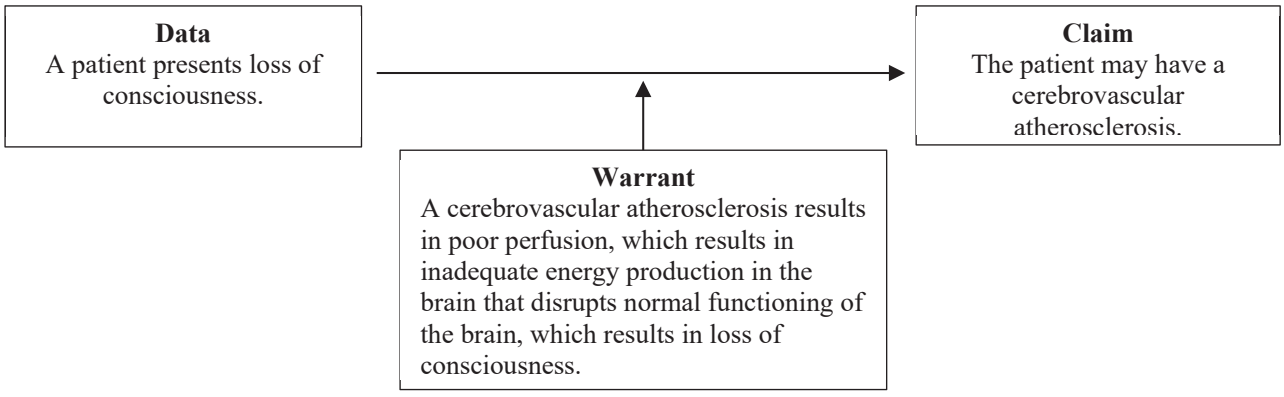

Figure 3. An example of argumentation for hypothesis generation.

The following discusses the structure of argumentation, including the three essential components of an argument based on Toulmin's (1958) model (a claim, data, and a warrant), in relation to the six phases of HDR adapted from Barrows's (1994) model of HDR—problem framing, hypothesis generation, inquiry strategy, data analysis and synthesis, diagnostic decision, and therapeutic decision—which are integrated in *The Argumentation-Integrated HDR Model* (see Figure 4, next page):

(1) Problem framing. Students form an initial concept of a patient's problem as an initial interpretation of identified patient information or cues considered important, which can be a claim in this phase. To support the claim, they use initial information or cues taken from observations or the patient's remarks mentioned in the initial encounter with the patient. The students explain why the identified information or cues are regarded as important for the patient as warrants for justifying the relevance of their claims and data.

(2) Hypothesis generation. Students' claims are hypotheses, such as basic mechanisms (e.g., physiological mechanisms) or disease entities that can be causes for the patient's problem. As data (evidence) for the claims, students describe a patient's complaints or symptoms presented in their initial encounter with the patient. To provide a justification that shows why the data are considered to support the claim, students provide warrants using pathophysiological mechanisms involved in the patient's problem. Students are encouraged to relate basic sciences to a fundamental understanding of the patient's problem at the organ, tissue, cellular or molecular level (Barrows, 1985).

(3) Inquiry strategy. Students' claims include what actions (questions, physical examination items, and laboratory or diagnostic tests) or further information can be necessary for validating their hypotheses. To support the claims, students provide the patient's information or cues organized by the hypotheses considered. Warrants involve basic mechanisms underlying hypotheses entertained or information about what the tests relay or what kind of information the actions will produce that would be helpful in strengthening or weakening their hypotheses.

(4) Data analysis and synthesis. Students' claims involve whether the patient's data is significant in relation to the hypotheses considered; in other words, the claims are interpretations of the patient's data obtained from the inquiry strategies. As data (evidence), the patient's answers to questions asked, the findings of the physical examinations, or the results of laboratory or diagnostic tests are included. To establish the connections between the claims and data (evidence), students construct warrants, using the knowledge of basic mechanisms, such as physiological or biochemical mechanisms, at the appropriate level (organ, tissue, cellular, or molecular).

(5) Diagnostic decision. Students make claims about decisions on the hypotheses most likely to be responsible for the patient's problem. As data (evidence) of their claims, students use significant patient data and its interpretations acquired in the analysis/synthesis process. To link the claims and evidence, they explain underlying responsible mechanisms involved in the patient's problem, describing the cause-effect chain of events, processes, and structures involved or present diagnostic criteria for the most likely disease of the patient.

(6) Therapeutic decision. Students make claims about decisions on treatment or management strategies of the patient's problem. As evidence to support their claims, they use their diagnostic decisions with the relevant patient's symptoms, signs, or clinical findings. As warrants, they articulate pathophysiological mechanisms relating biomedical knowledge to therapeutic interventions or refer to results of research showing whether or not standard medical treatments, such as surgery or radiation, are effective for patients who are diagnosed with the same disease in relation to evidence-based medicine (Dickinson, 1998; Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996). In this phase, students should be encouraged to make therapeutic decisions in terms of basic pathophysiological mechanisms (Barrows, 1985).

Collaborative Argumentation

Given that PBL requires students to work together to solve problems through small-group discussions (Barrows, 1985; Barrows & Tamblyn, 1980; Hmelo-Silver & Barrows, 2008), argumentation in this context is regarded as a collaborative process for problem solving and decision making (Baker, 2003). Means and Voss (1996) proposed that argumentation in the form of interactions between students plays a central role in students' reasoning and learning by stimulating the recognition and retrieval of knowledge, which can help them generate better inferences and engage in the problem-solving process. In other words, argumentation in a supportive dialogical setting is used as a vehicle for group members to formulate and share their ideas, to consider multiple perspectives on an issue, and to question, justify, and evaluate their own and others' arguments (Baker, 2003; Brown & Redmond, 2007; Golanics & Nussbaum, 2008).

During HDR processes, individual students in a small group can generate valid arguments, including a claim, data, and a warrant, by themselves, applying the argumentation-integrated HDR model, as well as contribute to collaborative argument construction by providing certain components that are missing in their group members' arguments or assisting others in constructing sound arguments through questioning. For example, when one student in a group only offered a claim

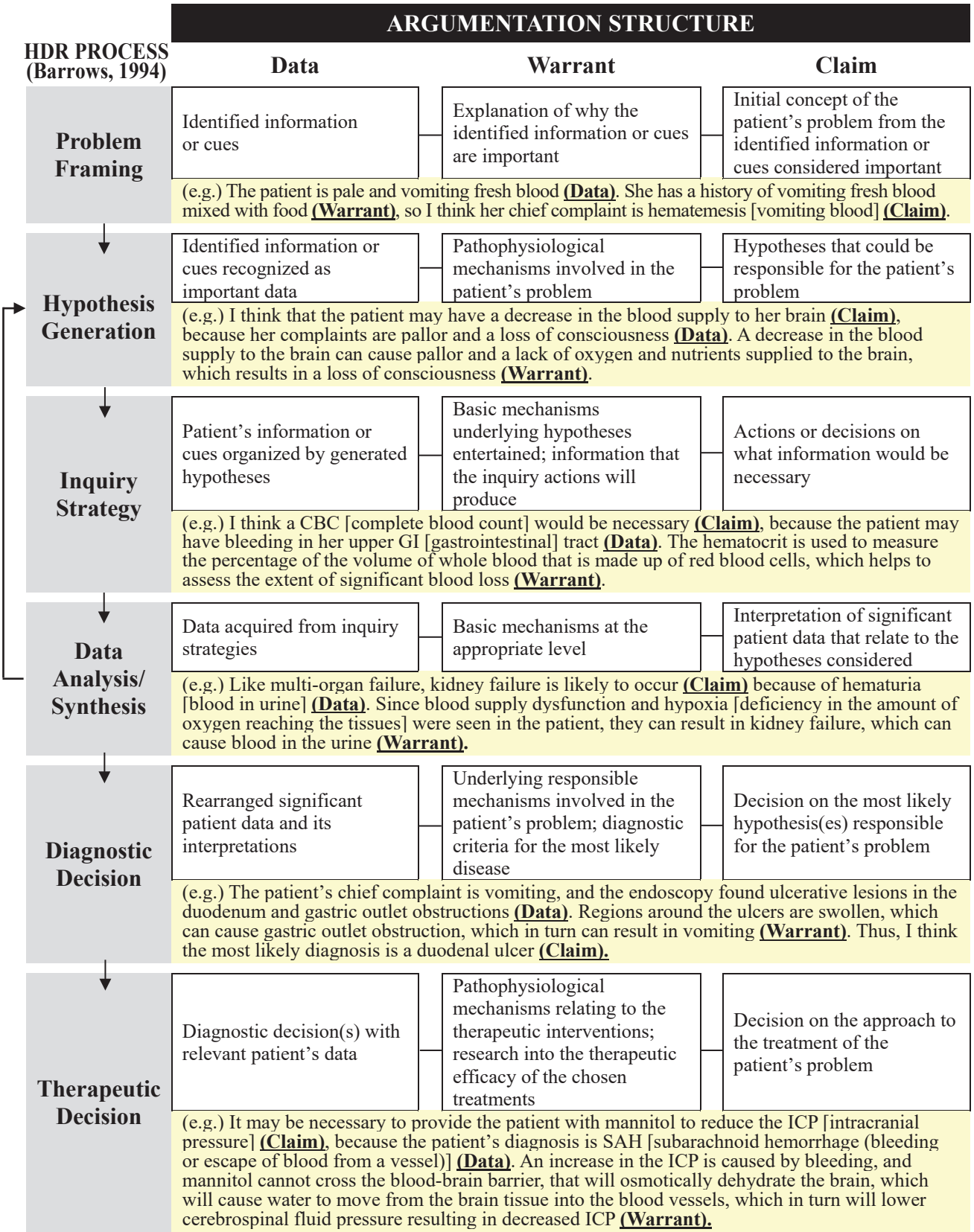

Figure 4. The structure of argumentation in relation to the hypothetico-deductive reasoning process: the argumentation-integrated HDR model.

without data and warrants during the inquiry strategy phase, such as "I think an EKG [electrocardiogram] would be necessary for the patient," other students could add data (e.g., "We need to test the myocardial infarction hypothesis") or warrants (e.g., "ST segment elevation or depression on EKG is typically indicative of myocardial infarction") for supporting the claim, or ask a question, such as "Why do you think the test is necessary?" Moreover, collaborative argumentation, according to the argumentation-integrated HDR model, will stimulate students to be aware of what they do not know or what additional information or knowledge is needed. For example, if in the situation mentioned above no students in the group could provide a warrant about why the test (an EKG) should be performed for the patient or feel certainty about his or her knowledge or information about the test, they would then determine their own group learning issues that need to be explored.

Instructional Recommendations of the Argumentation-integrated HDR Model

The argumentation-integrated HDR model that we constructed can further suggest the need for teaching and learning strategies to assist students in generating sound arguments during HDR processes in PBL. The following section will recommend four instructional strategies for promoting students' argumentation, including different types of scaffolding (e.g., supports provided by tutors and tools) based on previous studies and discuss how each strategy can be applied to the HDR processes of medical students in PBL.

An Aid for Understanding the Structure of Sound Arguments

It is essential for students to understand the primary components of an argument and their relationships with the other components so that they can construct sound arguments. Some students who have an undeveloped mental model of an argument structure may fail to recognize the claim-support relationship and produce arguments with missing or confused elements (Cerbin, 1988; Sampson & Clark, 2008; Zeidler, 1997). One of the validated strategies for supporting students' understanding of argument structures is the use of graphical argumentation tools, which serve as hard (Saye & Brush, 2002) or fixed (Azevedo, Cromley, & Seibert, 2004) scaffolds that are designed "based on typical student difficulties with a task" (Saye & Brush, 2002, p. 81). The strategy of graphically representing arguments helps students not only visualize the structure of arguments but also make the key elements of thinking or reasoning more explicit, which can guide a more rigorous argument construction (Buckingham Shum, MacLean, Bellotti, & Hammond, 1997; Chin & Osborne, 2010; Jonassen, 2011; Toth, Suthers, & Lesgold, 2002). Chin and Osborne's (2010) study suggested that students' use of a paper-based mode of an argument diagram based on Toulmin's (1958) model of argumentation assisted the students in organizing their thinking visually and linguistically, comprehending the nature of their own arguments, and identifying the strengths and weaknesses of their arguments. According to Suthers and Hundhausen's (2003) study, college students used one of three computer-based tools—a diagram, matrix, and text form—to represent their hypotheses, data, and relations between the hypotheses and data, while exploring causes of given science problems, and then were asked to write an essay about the results of their inquiry. The study found that the diagram users constructed more consistent relations between hypotheses and data in their essays than the matrix and text users did.

Argument diagrams offer a potential solution in promoting the quality of medical students' argumentation during HDR processes in PBL. For example, students should be encouraged to learn the structure of argumentation in relation to HDR phases and practice generating arguments individually or in small groups, using a paper-based or computer-based argument diagrams. In addition to the students' efforts, a PBL tutor training program or workshop would be needed to help tutors understand the structure of an argument for the HDR process and exercise argumentation using argument diagrams, which can develop their skills to support students' argumentation during HDR processes. Figure 5 (next page) shows an example of an argument diagram to be used for students and tutors to identify each of the three essential components (a claim, data, and a warrant) to be included in an argument for each phase of HDR, that was adapted from the argumentation-integrated HDR model.

Just-in-Time Guidance Through Questioning

Questioning is regarded as "one of the most fundamental cognitive components" (Jonassen, 2011, p. 285) that can promote students' reasoning (Graesser, Bagget, & Williams, 1996). In problem-solving learning environments such as PBL, teachers should serve as stimuli and engage students in problem-solving processes by asking questions rather than providing knowledge or explanations (Hmelo-Silver & Barrows, 2008). Such teachers' questioning can scaffold the development of students' argumentation skills through just-in-time supports based on teachers' ongoing monitoring of their students' learning progress or task performance (Andriessen, 2006; Jonassen, 2011). For example, in McNeill and Pimentel's (2010) study, students whose teacher frequently used open-ended questions (asking students to express their ideas and explain their reasoning) during discussions about the given science problem

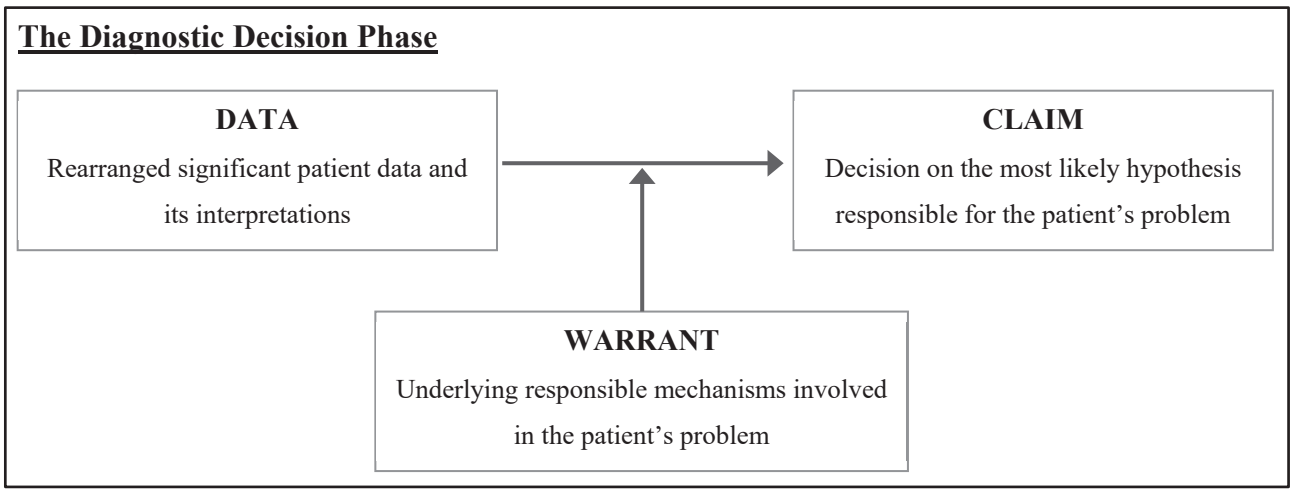

Figure 5. An example of an argument diagram.

were more likely to engage in scientific argumentation, providing data (evidence) and warrants to justify their claims. Additionally, Hmelo-Silver and Barrows (2008) suggested that PBL facilitators' questions that required medical students' deep reasoning and explanations, such as causal antecedent and consequence questions, during PBL sessions helped students build causal explanations of a patient's problem, employing knowledge of pathophysiological mechanisms.

When medical students engage in HDR processes in PBL, tutors should scaffold the students' argumentation by deliberately paying attention to their arguments and asking just-in-time questions so that the students can provide evidence and warrants to explain their ideas about the causes of a patient's problem (Barrows, 1985; Hmelo-Silver & Barrows, 2008). Possible questions tutors can use for promoting students' argumentation during each phase of HDR are presented in Table 1.

Supporting Elaboration on Structural Knowledge and Reasoning

Engaging students in elaborating on their structural knowledge can be used as an effective instructional strategy for promoting students' scientific argumentation. Scientific argumentation involves understanding and explaining relationships between concepts (Duschl & Osborne, 2002), which is related to structural knowledge defined as "the knowledge of how concepts within a domain are interrelated" (Jonassen, Beissner, & Yacci, 1993, p. 4). Concept mapping—a process of structuring and organizing concepts and making a propositional statement to link them—can be a tool for assisting learners in activating and representing their structural knowledge (Edmondson, 1994; Jonassen et al., 1993; Novak & Gowin, 1984; Rendas et al., 2006; Watson, 1989). In problem solving, the concept mapping approach can enable students to make salient the dynamic network of conceptual relationships, providing underlying explanations for a problem being investigated (Gonzalez, Palencia, Umana, Galindo, & Villafrade, 2008; Rendas et al., 2006). According to Hsu's (2004) research, an experimental group, who used concept mapping during PBL discussions in a nursing course, and a control group, who did not use concept mapping, were asked to draw a concept map about a clinical case on their final test. This study revealed that the experimental group had higher scores for their concept maps than the control group, which indicated that concept mapping facilitated the students in organizing patient data, applying concepts presented in nursing courses to a clinical case, and generating

Table 1. Examples of question prompts for enhancing students' argumentation in the hypothetico-deductive reasoning process.

HDR Phase	Example of Question Prompt (Barrows, 1985)
Problem Framing	"What information or cues seem important here?"
Hypothesis Generation	"What pathophysiological mechanisms might be involved in the patient's problem?"
Inquiry Strategy	"Why do you think that the questions (physical exams or tests) are necessary for the patient?"
Data Analysis/Synthesis	"What are basic mechanisms related to the test result?"
Diagnostic Decision	"How is your primary diagnosis supported by the symptoms/findings?"
Therapeutic Decision	"How can the treatment correct the patient's problem in terms of basic mechanisms?"

solutions to problems. Rendas et al. (2006) also found that medical students' use of concept mapping in a PBL pathophysiology course promoted the students' understandings of the relevant pathophysiological concepts involved in a patient's problem, and assisted them in generating hypotheses and gathering information for solving the problem.

Thus, in PBL, concept mapping can be a cognitive tool to assist medical students with clinical reasoning by helping them structure and organize information and relate concepts in the basic sciences to a patient's clinical presentations, which can enhance a pathophysiological understanding of a patient's problem (Addae, Wilson, & Carrington, 2012; Azer, 2005; Dee, Haugen, & Kreiter, 2014; Guerrero, 2001; Rendas et al., 2006). The following shows that creating a concept map as a diagram of the mechanisms of a patient's problem can be used as fixed scaffolding (Saye & Brush, 2002; Azevedo et al., 2004) to support students' coherent argument building during HDR processes:

(1) Hypothesis generation. Concept mapping can facilitate students to articulate data (evidence) and warrants for claims (hypotheses) in terms of pathophysiological mechanisms.

(2) Inquiry strategy. Students can discuss suggestions for further clinical investigations to validate their hypotheses while revisiting the hypotheses and pathophysiological mechanisms elicited in the concept map to justify their ideas about inquiry strategies.

(3) Data analysis and synthesis. Students can use the hypotheses and pathophysiological mechanisms included in the concept map to generate arguments for determining how the patient data obtained from inquiry strategies relate to the hypotheses and pathophysiological mechanisms entertained. They can also elaborate on the concept map, adding the significant patient data and detailed pathophysiological mechanisms to the previous concept map.

(4) Diagnostic and therapeutic decisions. The elaborated concept map that is focused around the final hypothesis can guide students in constructing arguments about diagnosis and therapeutic interventions for the patient's problem, which can promote building a comprehensive mechanistic diagram of the patient's problem.

In order to enhance students' scientific argumentation through a visual representation of mechanistic sequences for a patient's case, it would be necessary for tutors to employ timely supports by asking the students questions about or providing feedback on their concept mapping during HDR processes in PBL (Azer, 2005; Torre, Durning, & Daley, 2013).

Assessing the Quality of Students' Argumentation in the HDR Process

Assessing the quality of students' argumentation during HDR processes is essential for diagnosing their argumentation and providing effective guidance for promoting their argumentation (Jonassen, 2011). Toulmin's (1958) argumentation model has been used as a generic framework for analyzing and assessing the quality of argumentation in diverse disciplines. For example, Cho and Jonassen (2002) assessed students' arguments constructed during problem-solving sessions in an economics course, and Chin and Osborne (2010) performed a similar assessment in a science class; both used rubrics based on Toulmin's (1958) argumentation model.

Meanwhile, the argumentation-integrated HDR model previously proposed can be an effective tool for assessing medical students' arguments constructed during HDR processes. The structure of argumentation according to each phase of HDR represented in the model will be used for determining which components of an argument (a claim, data, or a warrant) were included in each of the students' arguments generated during each reasoning phase. For example, if a student produced an argument during the hypothesis generation phase such as, "The patient may have lung cancer, because he complains of hemoptysis and dyspnea," the argument would be dissected into two components—a claim (The patient . . . lung cancer) and data (because he . . . dyspnea)—in terms of the argument structure for the hypothesis generation phase. Then, identifying what combinations of the three primary components of an argument occur in the students' arguments, such as a claim, a claim coupled with data, and a claim coupled with data and a warrant, can be helpful for ascertaining the quality of the students' arguments; the quality of an argument including all of the three components is regarded as higher than the quality of an argument that only includes a claim. This assessment can allow for detecting the strengths and weaknesses of the students' argumentation as well as seeing if the students take coherent approaches to each phase of HDR, which helps to provide effective feedback for the students. Furthermore, the conceptual framework can guide students in self-reflection and self-assessment on their own argumentation during the HDR process in an effort to enhance the quality of their argumentation. Thus, assessing the quality of students' argumentation during HDR processes through the use of the argumentation-integrated HDR model will play a central role in promoting students' argumentation.

Implications and Conclusion

Constructing sound arguments and enhancing rational thought depends on the ability to provide justifications for one's claims, such as evidence and warrants (Lu, Chiu, & Law, 2011; von Aufschnaiter et al., 2008). Such argumentation skills are essential for students to carry out reasoned discussions in PBL, which can lead to quality reasoning and problem

solving. However, in a medical education context, students seemed to have challenges with meaningful argumentation and clinical reasoning processes during PBL (e.g., Ju et al., 2016). This has suggested the need for explicit guidance on how to develop and examine students' argumentation contextualized in clinical reasoning processes, such as HDR. In this study, we proposed a conceptual framework integrating the structure of argumentation, including the three essential elements of an argument (a claim, data, and a warrant) based on Toulmin's (1958) model, into each phase of HDR adapted from Barrows's (1994) model of clinical reasoning.

The argumentation-integrated HDR model articulated in the framework can be used as a means to help medical students identify the structure of argumentation for HDR processes and to analyze and assess medical students' argumentation during HDR processes in PBL. In addition, we discussed instructional recommendations based on the model for promoting students' argumentation concerning HDR processes during PBL, such as understanding argument structures, questioning, elaborating on structural knowledge, and assessing argumentation. These recommended strategies with specific examples of scaffolding can be implemented in faculty professional development and/or students' orientation prior to PBL and applied during PBL. For example, a training session offered to PBL tutors and students prior to PBL, including instruction on the argumentation-integrated HDR model, can provide guidelines for engaging students in argumentation and enhancing their HDR during PBL. Moreover, providing tutors with question prompts developed from the model can assist tutors in asking students questions according to each phase of HDR during PBL. Future research is needed to investigate the effects of the recommended strategies on the quality of students' argumentation and their HDR abilities.

Although our conceptual framework focused on a medical education context, it can be applicable to different disciplines using HDR as one of the primary reasoning strategies. The HDR approach has been used in science education, such as chemistry and biology (Lawson, 2000; Patel et al., 2005). For example, the structure of argumentation for PBL in biology may be developed through adapting and modifying the argumentation-integrated HDR model proposed in this paper in accordance with the biological problem context.

Moreover, the conceptual framework can be exemplary for building a framework or model combining an argumentation construct with a discipline-specific reasoning or problem-solving model beyond the medical education field. For example, PBL in legal education includes the following legal problem-solving processes: "problem finding, preliminary consideration of approaches to the problem, inquiry strategy, issue identification, research, legal analysis and solutions, and counselling or case management" (Kurtz, Wylie, & Gold, 1990, p. 804). Through identification of the nature and task of each process, a conceptual framework or model that integrates Toulmin's (1958) argumentation model into legal problem-solving processes can be developed. Likewise, in engineering education, students are encouraged to develop design thinking that engineers apply to devise effective solutions for meeting the needs of clients and users (Dym, Agogino, Eris, Frey, & Leifer, 2005). The design thinking process involves several phases, including "emphasize, define, ideate, prototype, and test" (d.school, 2013). A framework combining an argumentation model with design thinking processes may guide students in engaging in meaningful discussions during the process of design and thereby yield higher quality problem solving.

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