ENHANCING MEDICAL STUDENTS' ARGUMENTATION DURING HYPOTHETICO-DEDUCTIVE REASONING (HDR) IN PROBLEM-BASED LEARNING (PBL)

by

HYUN JUNG JU

(Under the Direction of Ikseon Choi)

ABSTRACT

Hypothetico-deductive reasoning (HDR) can be an essential learning activity as well as a learning outcome in problem-based learning (PBL). It is important for medical students to engage in argumentation so that they can provide scientific, causal explanations for a patient's problem and improve the quality of their scientific inquiry for problem solving about a patient's condition during PBL, which can foster their HDR abilities. However, there are very few studies focusing on the importance of medical students' argumentation in the process of HDR or instructional strategies to support the students' argumentation in PBL. This dissertation focuses on enhancing medical students' argumentation during HDR processes in PBL.

This dissertation consists of three journal-style manuscripts. The first manuscript (Chapter 2) describes a conceptual framework, the structure of argumentation including three essential components of an argument (a claim, data, and a warrant), in relation to each phase of HDR. The second manuscript (Chapter 3) presents a study that analyzes and assesses Korean medical students' argumentation during HDR processes in PBL. Arguments constructed by two small groups of seven to eight first-year preclinical students during PBL sessions were analyzed using the conceptual framework presented in Chapter 2. The results indicated the students predominantly generated arguments, including only claims without any proper justifications (data or warrants), during HDR processes. Based on the findings, the need for instructional strategies for enhancing the quality of medical students' argumentation during HDR processes in PBL was suggested. The third manuscript (Chapter 4) presents a study that examines the effects of instruction on the structure of argumentation and question prompts (ISA-QP) on medical students' argumentation during HDR processes in PBL. The findings of the study indicated that providing the instruction on the structure of argumentation and question prompts (ISA-QP) improved the quality of students' argumentation and contributed to the quality of experiences with PBL for students and tutors. The dissertation concludes with future research directions in Chapter 5.

INDEX WORDS: Argumentation, Hypothetico-deductive reasoning, Problem-based learning, Medical education

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DEDICATION

This dissertation is dedicated to the memory of my father, Byeong-Gyu Ju, and to my mother, Gyeongsuk Park, my uncle, Young Chan Park, my older brother, Heui Young Ju, and my sister-in-law, Eun Ju Jung. Your endless love, sacrifice, and tremendous encouragement and support gave me strength to overcome many challenges and complete this journey.

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CHAPTER 1

INTRODUCTION

Clinical reasoning is the most critical skill that a physician must possess (Croskerry, 2009). It involves the problem solving that occurs when a physician meets a patient in a clinical setting (Barrows & Tamblyn, 1980). According to Patel, Arocha, and Zhang (2005), reasoning and decision-making mistakes are crucial causes of medical errors: "The failure and success of reasoning strategies and skills can be traced back to their sources—education" (p. 741). Kempainen, Migeon, and Wolf (2003) also pointed out that most physicians who did not receive formal instruction in clinical reasoning during their training would be more likely to commit mistakes in reasoning in their practice. Thus, many medical schools have attempted to implement educational methods or curricula that can help produce doctors capable of evaluating and managing patients with medical problems effectively, efficiently, and humanely (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Cooke, Irby, & O'Brien, 2010). Among the various approaches, problem-based learning (PBL) has been adopted to assist medical students in developing clinical reasoning, *hypothetico-deductive reasoning*, and bridging the gap between basic scientific knowledge learned in the classroom and clinical knowledge learned in complex clinical situations (Barrows, 1985, 1994, 1996; Barrows & Tamblyn, 1980; Patel et al., 2005). Hypothetico-deductive reasoning (HDR) includes the generation of hypotheses and the testing of those hypotheses (Higgs & Jones, 1995) and can be used when problem solvers have a lack of domain knowledge and clinical experiences (Patel et al., 2005). The HDR model can provide a useful framework for helping medical students, who lack clinical experiences and routine methods of problem solving and find most clinical situations unfamiliar and problematic, diagnose a patient's clinical problems (Elstein, 1995). The HDR model is incorporated into a PBL method to serve as an appropriate approach for helping students create an adequate structure for developing their medical problem solving skills in the early years of their training (Groves, 2007; Hmelo, 1998; Norman, Brooks, Colle, & Hatala, 1999; Patel et al., 2005).

In PBL, medical students in small groups of four to eight people are encouraged to work together for medical problem solving through group discussions. It is, therefore, necessary for them to engage in the HDR process through expressing their own ideas, negotiating alternative ideas to a problem with others, and providing reasons and explanations to support the ideas (Hmelo-Silver & Barrows, 2008). In other words, this involves argumentation that encompasses a process of constructing, exchanging, and evaluating claims and providing justifications for the claims (Blair, 2011; Cho & Jonassen, 2002; Jonassen, 2011; Mochales & Moens, 2011; Nussbaum, 2011; Nussbaum & Edwards, 2011; Walton, 2007). In order for medical students to generate sound arguments during HDR processes in PBL, it would be important for them to understand the nature and the structure of argumentation and learn how to structure arguments. Argumentation consists of six components: (1) a claim; (2) data (evidence) for supporting the claim; (3) a warrant for justifying the connection between the data and claim; (4) a backing for providing a rationale for the warrant; (5) a rebuttal that would weaken the claim; and (6) a qualifier for expressing limited certainty of the claim (Toulmin, 1958, 2003). The soundness of an argument depends on the ability to provide three components —a claim, data, and a warrant— of the six components of argumentation (Toulmin, 1958, 2003; von Aufschnaiter, Erduran, Osborne, & Simon, 2008). This may suggest that students should be facilitated to use at least the three primary elements (a claim, data, and a warrant) in constructing their arguments.

Additionally, key to scientific inquiry is the ability to produce reasoned arguments, including observational data and theoretical explanations for a phenomenon being investigated (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Newton, Driver, & Osborne, 1999; Siegel, 1995). PBL is expected to develop students' abilities to integrate biomedical and clinical knowledge to reason from clinical information to scientific principles and theories (Barrows, 1985, 1994, 1996; Barrows & Tamblyn, 1980; Boshuizen & Schmidt, 1992; Prince, van de Wiel, Scherpbier, van der Vleuten, & Boshuizen, 2000), which may empower the HDR process. Thus, it would be necessary to encourage medical students to engage in argumentation so that they can provide scientific, causal explanations for a patient's problem and improve the quality of their scientific inquiry for problem solving about a patient's condition during PBL. However, there are very few studies focusing on the importance of medical students' argumentation in the process of HDR or instructional strategies to support the students' argumentation in PBL.

Therefore, the purpose of this dissertation study is to find ways of enhancing medical students' argumentation in a problem-based learning approach, which could foster their hypothetico-deductive reasoning (HDR) abilities. For this purpose, a conceptual framework of argumentation in relation to each HDR process was developed. Also, a study in assessing medical students' argumentation during HDR processes in PBL was conducted through analyses of their argumentation. Based on the findings of the study, a study was conducted to develop instruction on the structure of argumentation and question prompts (ISA-QP) that can promote medical students' argumentation and to investigate the effects of the ISA-QP on the students' argumentation during HDR processes in PBL. This dissertation study will provide a clear understanding of the structure of argumentation in relation to the HDR process and guidelines for facilitating students' engagement in argumentation and enhancing their hypothetico-deductive reasoning during PBL.

Dissertation Overview

This dissertation consists of three manuscripts that are publication-ready. The first paper (Chapter 2), *The Role of Argumentation in Hypothetico-Deductive Reasoning (HDR) during Problem-Based Learning (PBL): A Conceptual Framework*, attempts to develop a framework of argumentation with respect to hypothetico-deductive reasoning (HDR) processes. The paper presents general processes of HDR that physicians use for a patient's medical problem solving and the importance of basic mechanisms for medical students engaged in HDR during PBL. Also, the definition of argumentation and Toulmin's (1958, 2003) model of argumentation are presented, and the structure of argumentation in relation to each process of HDR adapted from Barrows' (1994) model of HDR is developed based on the three essential components of argumentation (a claim, data, and a warrant) proposed by Toulmin (1958, 2003). Finally, instructional recommendations to promote students' argumentation skills during HDR processes are discussed.

The second paper (Chapter 3) is *Assessing Korean Medical Students' Argumentation during Hypothetico-Deductive Reasoning (HDR) in Problem-Based Learning (PBL)*. Based on the structure of argumentation in relation to each phase of HDR proposed in the first paper (Chapter 2), Korean medical students' argumentation was analyzed. The analysis focused on the quantity and quality of arguments constructed during each phase of HDR. The results indicated students' lack of generating high quality arguments, including the three primary components of an argument. Based on the findings, instructional strategies for enhancing the quality of medical students' argumentation during HDR processes in PBL are suggested.

The third paper (Chapter 4), *Enhancing Medical Students' Argumentation during Hypothetico-Deductive Reasoning (HDR) in Problem-Based Learning (PBL)*, presents a study that aims to examine the effects of instruction on the structure of argumentation and question prompts (ISA-QP) provided for medical students and PBL tutors on students' argumentation during HDR processes in PBL. This study was conducted at a Korean medical school and employed a mixed-methods research design, incorporating a quasi-experimental method and a qualitative approach through semi-structured interviews. The quality of students' argumentation was analyzed and compared between a control group of first-year preclinical students who did not receive the ISA-QP in 2014 and an experimental group of first-year preclinical students who received the ISA-QP in 2015, using statistical analysis methods. Semi-structured interviews with eight students from the experimental group and eight tutors were conducted to gain a deeper understanding of the impact of the ISA-QP on students' argumentation. Findings of this study demonstrated that the instruction on the structure of argumentation and question prompts (ISA-QP) improved the quality of students' argumentation during the HDR process and contributed to the quality of experiences with PBL for students and tutors.

Finally, Chapter 5 includes a summary of key ideas from the three manuscripts. As this dissertation study has served as an initial step toward the goal of enhancing medical students' argumentation during PBL, this chapter also describes the limitations of the studies and suggestions for future research.

References

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years.* New York, NY: Springer.

Barrows, H. S. (1994). *Practice-based learning: Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*, *68*(3), 3–12. doi:10.1002/tl.37219966804

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York, NY: Springer.

Blair, J. A. (2011). Argumentation as rational persuasion. *Argumentation*, *26*(1), 71–81. doi:10.1007/s10503-011-9235-6

Boshuizen, H. P., & Schmidt, H. G. (1992). On the role of biomedical knowledge in clinical reasoning by experts, intermediates and novices. *Cognitive Science, 16*(2), 153–184. doi:10.1207/s15516709cog1602_1

Cho, K. L., & Jonassen, D. H. (2002). The effects of argumentation scaffolds on argumentation and problem solving. *Educational Technology Research and Development*, *50*(3), 5–22. doi:10.1007/BF02505022

Cooke, M., Irby, D. M., & O'Brien, B. C. (2010). *Educating physicians: A call for reform of medical school and residency.* San Francisco, CA: Jossey-Bass.

Croskerry, P. (2009). A universal model of diagnostic reasoning. *Academic Medicine*, *84*(8), 1022–1028. doi:10.1097/ACM.0b013e3181ace703

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. doi:10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38*(1), 39–72. doi:10.1080/03057260208560187

Elstein, A. S. (1995). Clinical reasoning in medicine. In J. Higgs & M. A. Jones (Eds.), *Clinical reasoning in the health professions* (pp. 49-59). Boston, MA: Butterworth-Heinermann.

Groves, M. (2007). The diagnostic process in medical practice: The role of clinical reasoning. In E. M. Vargios (Ed.), *Educational psychology research focus* (pp. 133-184). New York, NY: Nova Science Publisher.

Higgs, J., & Jones, M. A. (Eds.). (1995). *Clinical reasoning in the health professions*. Boston, MA: Butterworth-Heinermann.

Hmelo, C. E. (1998). Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *The Journal of the Learning Sciences, 7*(2), 173–208. doi:10.1207/s15327809jls0702_2

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction, 26*(1), 48–94. doi:10.180/07370000701798495

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments.* New York, NY: Routledge.

Kempainen, R. R., Migeon, M. B., & Wolf, F. M. (2003). Understanding our mistakes: A primer on errors in clinical reasoning. *Medical Teacher, 25*(2), 177–181. doi:10.1080/0142159031000092580

Mochales, R., & Moens, M. F. (2011). Argumentation mining. *Artificial Intelligence and Law, 19*(1), 1–22. doi:10.1007/s10506-010-9104-x

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education*, *21*(5), 553–576. doi:10.1080/095006999290570

Norman, G. R., Brooks, L. R., Colle, C. L., & Hatala, R. M. (1999). The benefit of diagnostic hypotheses in clinical reasoning: Experimental study of an instructional intervention for forward and backward reasoning. *Cognition and Instruction, 17*(4), 433–448. doi:10.2307/3233841

Nussbaum, E. M. (2011). Argumentation, dialogue theory, and probability modeling: Alternative frameworks for argumentation research in education. *Educational Psychologist*, *46*(2), 84–106. doi:10.1080/00461520.2011.558816

Nussbaum, E., & Edwards, O. V. (2011). Critical questions and argument stratagems: A framework for enhancing and analyzing students' reasoning practices. *Journal of the Learning Sciences*, *20*(3), 443–488. doi:10.1080/10508406.2011.564567

Patel, V. L., Arocha, J. F., & Zhang, J. (2005). Thinking and reasoning in medicine. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 727–750). New York, NY: Cambridge University Press.

Prince, K., van de Wiel, M., Scherpbier, A., van der Vleuten, C., & Boshuizen, H. (2000). A qualitative analysis of the transition from theory to practice in undergraduate training in a PBL medical school. *Advances in Health Sciences Education, 5*(2), 105–116.

Siegel, H. (1995). Why should educators care about argumentation? *Informal Logic*, *17*(2), 159–176.

Toulmin, S. (1958). *The uses of argument.* Cambridge: Cambridge University Press.

Toulmin, S. (2003). *The uses of argument.* Cambridge: Cambridge University Press.

von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching, 45*(1), 101–131. doi:10.1002/tea.20213

Walton, D. (2007). *Dialog theory for critical argumentation.* Philadelphia, PA: John Benjamins.

CHAPTER 2

THE ROLE OF ARGUMENTATION IN HYPOTHETICO-DEDUCTIVE REASONING (HDR) DURING PROBLEM-BASED LEARNING (PBL): A CONCEPTUAL FRAMEWORK[1]

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Abstract

One of the important goals of problem-based learning (PBL) is to enhance medical students' hypothetico-deductive reasoning (HDR) through argumentation during small group discussions. The purpose of this paper was to develop a conceptual framework about the role of argumentation in the HDR process during PBL. The framework involved the structure of argumentation, including three basic components of argumentation based on Toulmin's argumentation model (a claim, data, and a warrant), within HDR processes proposed by Barrows. The structure of argumentation in relation to HDR processes can provide a framework for analyzing and evaluating medical students' argumentation during HDR processes. Instructional suggestions for supporting medical students' argumentation, which can help them enhance their HDR abilities, 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 continue with the student-centered inquiry process of understanding or solving a problem (Barrows & Tamblyn, 1980; Schwartz, Mennin, & Webb, 2001). PBL was initially developed and applied in a medical education context in the late 1960s in response to the dissatisfying results of traditional medical education—where students often acquire large amounts of information organized around isolated subjects by lectures, but they often have difficulty recalling and applying it in clinical situations (Schmidt & de Volder, 1984; Spaulding, 1969). The PBL method expects medical students to acquire knowledge in the context of patients' problems, which can support the retrieval and application of this knowledge later in their clinical practice, and to enhance students' clinical reasoning skills that encompass the ability to evaluate a patient's problem and to make decisions about the management of the problem in association with the application of basic science and clinical knowledge (Barrows, 1985, 1996; Barrows & Tamblyn, 1980). For clinical reasoning, the PBL method has adopted a hypothetico-deductive reasoning (HDR) model used by physicians who solve difficult, unfamiliar, or complex medical problems (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Sefton, Gordon, & Field, 2008). That is, medical students are encouraged to practice and develop HDR during PBL sessions (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Patel, Groen, & Norman, 1993). Students are first presented with a patient's medical problem through a paper, video, or simulated (standardized) patient before any study occurs in the area of the problem, and they generate multiple hypotheses to explain causes of the patient's problem, conduct inquiries to test their hypotheses, and make a diagnostic decision and treatment plans for the patient. Although PBL is expected to develop students' clinical reasoning skills in theory when compared to traditional methods, there have been gaps between theoretical outcomes and those actually obtained in practice (Hung, 2011). For example, there are inconsistent findings among several studies regarding the effects of PBL on clinical reasoning skills. Albanese and Mitchell's (1993) study found that the PBL program had a positive impact on students' clinical performance, whereas Colliver (2000) suggested no conclusive evidence of any beneficial effects of PBL on students' diagnostic reasoning skills. Also, 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 (Patel et al., 1993). As discussed earlier, many previous studies have examined the effectiveness of PBL in the clinical reasoning skills of medical students, but very few studies have focused on specific strategies or guidelines to enhance HDR skills during PBL. Thus, as HDR plays a key role in learning and problem solving in PBL, it is necessary to research ways to empower students' HDR in PBL.

In PBL, medical students in small groups are encouraged to work together in order to solve a patient's problem (Barrows, 1985; Barrows & Tamblyn, 1980; Hmelo, 1998; Hmelo-Silver & Barrows, 2008; van Berkel & Dolmans, 2006). The medical problem solving may be engaged by some form of argumentation (Belland, 2010; Cerbin, 1988; Jonassen, 2011; Jonassen & Kim, 2009; Kuhn, 1992). A pedagogical emphasis on argumentation is consistent with general education goals that seek to enhance students' reasoning abilities, including paying attention to reasons, evaluating the quality and relevance of the reasons, and forming valid ideas or beliefs based on the reasons (Siegel, 1995). 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 addition, argumentation can often be regarded more as cooperative processes for exploring a problem than as conflicts with one another in collaborative problem solving situations (Baker, 2003). In PBL, medical students' argumentation needs to be facilitated in a way to develop their HDR skills. Students in a small group should be able to construct, exchange, and evaluate their ideas and provide justifications for the ideas, applying basic scientific knowledge to clinical contexts, taking a coherent approach to diagnostic inquiry, and building a collective model of a patient's illness during HDR processes (Frederiksen, 1999; Hmelo-Silver & Barrows, 2008). In order to support medical students' argumentation in PBL, it is important to understand the role of argumentation in the HDR process. Several studies (e.g., Belland, Glazewski, & Richardson, 2011) have explored scaffolding strategies to foster students' argumentation skills for ill-structured problem solving. However, research focusing on the importance of medical students' argumentation or specific argumentation strategies with regard to the process of HDR in PBL is especially scarce.

Thus, the purpose of this paper was to develop a conceptual framework that could explain the structure of argumentation contextualized in each phase of HDR during PBL and that could provide possible pedagogical recommendations for enhancing students' argumentation in the HDR process. For this purpose, this paper will discuss the following: (1) Hypothetico-Deductive Reasoning (HDR), (2) Hypothetico-Deductive Reasoning (HDR) in PBL, (3) Argumentation, and (4) A framework to Integrate Argumentation into the HDR Process. This study will provide insights into ways for promoting medical students' argumentation, which in turn could develop students' HDR skills in PBL. It will also guide PBL tutors in promoting their role as facilitators for students' engagement in argumentation.

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). Medical reasoning as hypothetico-deductive is characterized as the embodied scientific method (Barrows & Tamblyn, 1980; Patel, Evans, & Groen, 1989). *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" (UF, 2012). In medicine, HDR is used to "evaluate and manage a patient's medical problems" (Barrows & Tamblyn, 1980, p. 19). Physicians' hypothetico-deductive reasoning may incorporate the following phases (Barrows, 1985, 1994; Barrows & Tamblyn, 1980):

(1) Problem framing: 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 perceived initial cues.

(2) Generation of multiple hypotheses: Based on the perceived 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. The significant patient's 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. When deciding no more helpful data can be gotten 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 not linear but iterative (see Figure 2.1). The HDR processes 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; Terry & Higgs, 1993).

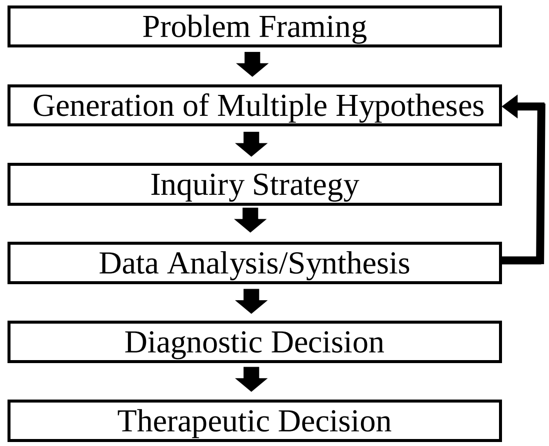

Figure 2.1. The hypothetico-deductive reasoning process. Adapted from Barrows, 1994.

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, Arocha, & Zhang, 2005). 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 and 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

In PBL, medical students are encouraged to acquire basic scientific knowledge in the context of specific cases posed as clinical problems so that they can better retain, apply, and retrieve the knowledge in their future clinical practices; PBL is supposed to develop students' abilities to integrate biomedical and clinical knowledge to reason from clinical information to scientific principles and theories (Barrows, 1994, 1996; Barrows & Tamblyn, 1980; Boshuizen & Schmidt, 1992; Prince, van de Wiel, Scherpbier, van der Vleuten, & Boshuizen, 2000).

Clinical knowledge concerns the knowledge of the attributes of diseases, which relates to symptoms and signs of and treatment or management approaches to the diseases (Boshuizen &

Schmidt, 1992; Diemers, van de Wiel, Scherpbier, Heineman, & Dolmans, 2011; Patel, Evans, & Groen, 1989; van de Wiel, Boshuizen, & Schmidt, 2000). In contrast, biomedical knowledge includes the knowledge of the pathological principles, mechanisms, or processes involved in the representations of diseases (Boshuizen & Schmidt, 1992; Diemers et al., 2011; Patel et al., 1989; Woods, Brooks, & Norman, 2005, 2007). 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 cumulated by their clinical experiences, rather than biomedical knowledge, to represent and diagnose a patient's problem (Patel et al., 1989), but when confronted with an unfamiliar patient's case, they would employ their knowledge of basic science to try to connect clinical features that are not easily explained (van de Wiel et al., 2000; Woods et al., 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, 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 could assist students in creating a coherent mental representation of a clinical case when the clinical features become disorganized (Boshuizen & Schmidt, 1992; Woods, 2007). Causal, pathophysiological mechanisms of a patient's problem provide an efficient means of verifying and explaining diagnostic hypotheses (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). Also, students 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, and similar difficulties probably also occur during clinical and early postgraduate training (Boshuizen & Schmidt, 1992; Diemers et al., 2011; Prince et al., 2000). Also, Patel et al. (1989) found that preclinical students applied basic science information to a 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. This will indicate that scaffolding strategies may need to be sought so that students can build a causal, scientific mechanism that integrates relevant information learnt to explain the pathophysiological processes in a patient's case during clinical reasoning processes.

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 justification for the claims (Blair, 2011; Cho & Jonassen, 2002; Jonassen, 2011; Mochales & Moens, 2011; Nussbaum, 2011; Nussbaum & Edwards, 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). An argument is the result of reasoning and consists of a series of propositions (Cerbin, 1988; Nussbaum, 2011). For problem solving, students' ability to construct valid arguments about how they investigated a problem and their ideas for solutions to the problem can provide a means for assessing their problem-solving 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 (Bligh, 2000; Driver et al., 2000; Jonassen, 2011; Nussbaum, 2011; Siegel, 1995). Toulmin's model (1958, 2003) has been very influential in the field of argumentation theory (Andrews, 2005; Jiménez-Aleixandre & Rodriguez, 2000; Jonassen, 2011; Nussbaum, 2011). Toulmin (1958, 2003) suggested a model that describes the constitutive elements of argumentation and represents the functional relationships among them. According to Toulmin's model (1958, 2003), there are 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). For Toulmin's model, central to the soundness of arguments is data that supports claims and warrants that act as inferential 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, 2003). Furthermore, Toulmin (1958, 2003) 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 would weaken or invalidate the claim; and (3) a qualifier: limited certainty of the claim, which is usually constituted by 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, 2003). Toulmin’s model 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 would help students learn how an argument should unfold in discussion and make their warrants more explicit (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 (Bell & Linn, 2000; Jiménez-Aleixandre & Rodriguez, 2000; McNeill, Lizotte, Krajcik, & Marx, 2006). The students’ challenges with argumentation could be attributed to students’ naïve conceptions of argument structures (Cerbin, 1988; Zeidler, 1997), students’ 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 for fostering students’ argumentation in the classroom (Belland et al., 2011; Driver et al., 2000; Newton et al., 1999). It would be necessary to develop strategies to ease the students’ challenges and foster students’ argumentation.

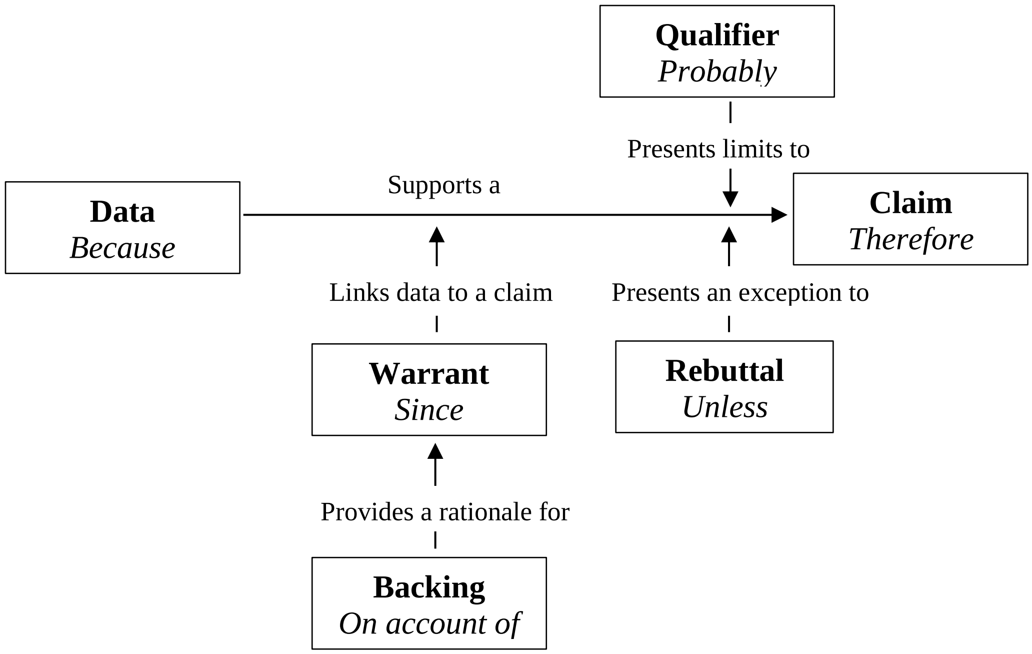

Figure 2.2. The structure of an argument. Adapted from Toulmin (1958, 2003).

A 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 can explain how the generic structure of argumentation could be contextualized in each phase of HDR.

Within the context of HDR processes, it is important for medical students to engage in argumentation, including related evidence for their claims and reasoning from the claims and evidence, integrating biomedical and clinical knowledge, so as to provide scientific, causal explanations for a patient’s problem and improve the quality of their scientific inquiry for problem solving about a patient’s condition. That is, 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, 2003) argumentation model in their arguments: claim(s), data (evidence), and warrant(s). The claim can be a statement that answers the original question or problem; for example, when provided with a patient’s problem, students could generate hypotheses about possible causes for the patient's 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 could include pathological and physiological principles, mechanisms, or processes underlying clinical features.

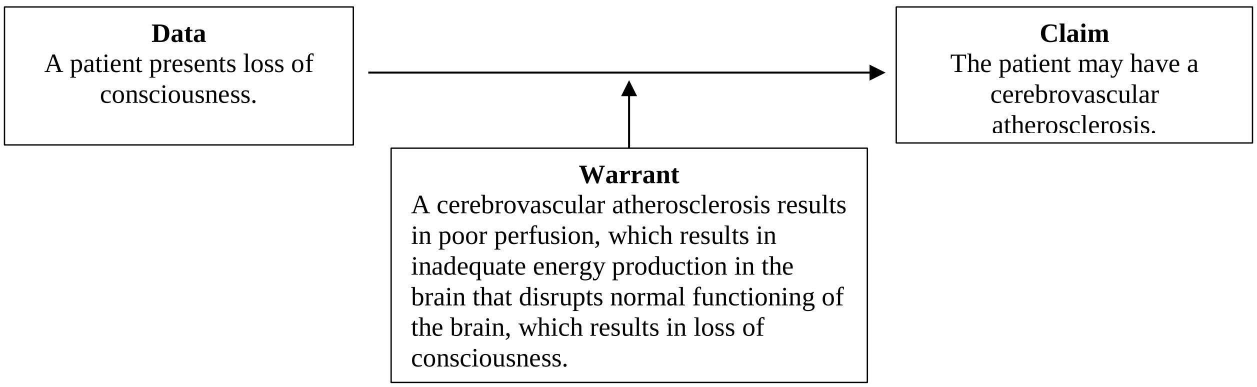

Figure 2.3. An example of argumentation for hypothesis generation.

The structure of argumentation, including the three essential components of argumentation based on Toulmin's (1958, 2003) model (a claim, data, and a warrant), in relation to the six phases of HDR adapted from Barrows' (1994) model of HDR—problem framing, hypothesis generation, inquiry strategy, data analysis and synthesis, diagnostic decision, and therapeutic decision—is discussed as follows (see Figure 2.4):

(1) Problem framing: Students form an initial concept of a patient's problem as an initial information interpretation with identified patient information or cues considered important, which can be a claim in this phase. To support the claim, they can use initial information or cues taken from observations or the patient's remarks mentioned in the initial encounter with the patient. The students may 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 would be hypotheses responsible for a patient's problem. As data (evidence) for the claims, students may 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 evidence to support the claim, students may 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 may include what actions (questions, physical examination items, and laboratory or diagnostic tests) or further information would be necessary for validating their hypothesis(es). To support the claims, students would provide the patient's information or cues organized by hypotheses entertained. Warrants could involve basic mechanisms underlying hypotheses entertained or information about what the tests relay and 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 may involve whether the patient's data is significant in relation to the hypotheses considered; in other words, the claims can be data interpretations. As data (evidence), the patient's answers to questions asked, the findings of the physical examinations or the results of laboratory or diagnostic tests may be included. To establish the connections between the claims and data (evidence), students would construct warrants using pathophysiological (pathological, immunological, and microbiological) mechanisms at the appropriate level (organ, tissue, cellular, or molecular).

HDR PROCESS (Barrows, 1994)	ARGUMENTATION STRUCTURE: Data	Warrant	Claim
Problem Framing	Identified information or cues	Explanation why the identified information or cues are important	Initial concept of the patient's problem from the identified information or cues considered important
	e.g.) The patient is pale and vomiting fresh blood **(Data)**. She has a history of vomiting fresh blood mixed with food **(Warrant)**, so I think her chief complaint is hematemesis **(Claim)**.		
Hypothesis Generation	Identified information or cues recognized as important data	Pathophysiological mechanisms involved in the patient's problem	Hypotheses that could be responsible for the patient's problem
	e.g.) I think that the patient may have a decrease in the blood supply to her brain **(Claim)**, because her complaints are pallor and a loss of consciousness **(Data)**. A decrease in the blood supply to the brain can cause pallor and a lack of oxygen and nutrients supplied to the brain, which results in a loss of consciousness **(Warrant)**.		
Inquiry Strategy	Patient's information or cues organized by generated hypotheses	Basic mechanisms underlying hypotheses entertained; information that the inquiry actions will produce	Actions or decisions on what information would be necessary
	e.g.) I think a CBC [complete blood count] would be necessary **(Claim)**, because the patient may have bleeding in her upper GI tract **(Data)**. The hematocrit is used to measure the percentage of the volume of whole blood that is made up of red blood cells, which helps to assess the extent of significant blood loss **(Warrant)**.		
Data Analysis/ Synthesis	Data acquired from inquiry strategies	Basic mechanisms at the appropriate level	Interpretation on significant patient data that relate to the hypotheses considered
	e.g.) Like multi-organ failure, kidney failure is likely to occur **(Claim)** because of hematuria **(Data)**. Since blood supply dysfunction and hypoxia were seen in the patient, they can result in kidney failure, which can cause blood in the urine **(Warrant).**		
Diagnostic Decision	Rearranged significant patient data and its interpretations	Underlying responsible mechanisms involved in the patient's problem; diagnostic criteria for the most likely disease	Decision on the most likely hypothesis(es) responsible for the patient's problem
	e.g.) The patient's chief complaint is vomiting, and as results of the endoscopy, ulcerative lesions in the duodenum and gastric outlet obstructions were found **(Data)**. Regions around the ulcers are swollen, which can cause gastric outlet obstruction, which in turn can result in vomiting **(Warrant)**. Thus, I think the most likely diagnosis is a duodenal ulcer **(Claim).**		
Therapeutic Decision	Diagnostic decision(s) with relevant patient's data	Pathophysiological mechanisms relating to the therapeutic interventions; research into the therapeutic efficacy of the chosen treatments	Decision on the approach to the treatment of the patient's problem
	e.g.) It may be necessary to provide the patient with mannitol to reduce the ICP [intracranial pressure] **(Claim)**, because the patient's diagnosis is SAH [subarachnoid hemorrhage] **(Data)**. An increase in the ICP is caused by bleeding, and mannitol cannot cross the blood-brain barrier, that will osmotically dehydrate the brain, which will cause water to move from the brain tissue into the blood vessels, which in turn will lower cerebrospinal fluid pressure resulting in decreased ICP **(Warrant).**		

Figure 2.4. The structure of argumentation in relation to the hypothetico-deductive reasoning process.

(5) Diagnostic decision: Students would make claims about a decision(s) on the hypothesis(es) most likely to be responsible for the patient's problem. As data (evidence) of their claims, students may use significant patient data and its interpretations acquired in the analysis/synthesis process. To link the claims and evidence, they would 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 may make claims about decisions on treatment or management strategies of the patient's problem. As evidence to support their claims, they could substantiate their diagnostic decision(s) with the relevant patient's symptoms, signs, or clinical findings. As warrants, they may 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 et al., 1996). In this phase, students should be encouraged to make therapeutic decisions in terms of basic pathophysiological mechanisms (Barrows, 1985).

"Reasoning is fundamentally dialogical" (Anderson et al., 2001, p. 2); reasoning inside one's mind consists of a flow of propositions within a discourse of reasoned argumentation (Anderson et al., 2001; Kuhn, 1992). Social interaction is regarded as a primary means for promoting students' reasoning (Anderson et al., 2001; Kuhn, 1992; Resnick, Salmon, Zeitz, & Wathen, 1993; Reznitskaya et al., 2001). Kuhn, Shaw, and Felton (1997) found that participation in a group discussion enhanced the reasoning abilities of participants, including an increased range of arguments, the propensity to consider counterarguments, and metacognitive awareness of multiple perspectives. In PBL, 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, 2007). In addition, argumentation can provide local and global discourse frameworks that allow medical students to engage in the HDR process (Frederiksen, 1999). The local discourse framework involves students' arguments: students' propositions, inferences that relate each proposition expressed by a student to previous propositions, and the sequences of the inferences that produce reasoning chains for causal explanations of the patient's problem (Frederiksen, 1986, 1999). The global discourse framework for diagnostic problem solving in PBL includes a structure of basic science and clinical knowledge to establish a model of a clinical case (e.g., pathophysiological mechanisms of disease) and a structure of diagnostic inquiry procedures (e.g., hypothesis generation) (Frederiksen, 1999). Thus, facilitating medical students to construct valid arguments can help their collaborative knowledge building that is relevant to causal explanations for a patient's clinical problem and guide scientific inquiry processes, which could support students' HDR.

Instructional Recommendations to Promote Students' Argumentation in HDR

This paper aimed to develop a conceptual framework explaining the role of argumentation in the HDR process in PBL. This framework also provides pedagogical insights on how students' HDR abilities can be enhanced through supporting their argumentation. Based on our conceptual framework, suggestions for pedagogical strategies to enhance students' argumentation are presented in the following section.

An Aid for Understanding the Structure of Sound Arguments

It is essential for students to understand primary components of an argument and its relationship among the components so that they can construct sound arguments. Some students with 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' understandings of argument structures can be using graphical argumentation tools. The strategy of graphically representing arguments assists students in seeing the structure of the argument, which can guide a more rigorous argument construction (Buckingham Shum, MacLean, Bellotti, & Hammond, 1997; Chin & Osborne, 2010; Jonassen, 2011). The cognitive power of external representations through graphical forms helps users extract information encoded in the representations; in other words, the graphical forms can guide the users in building arguments with making the key elements of thinking or reasoning explicit (Toth, Suthers, & Lesgold, 2002). There are many studies regarding visual tools that scaffold students' argumentation. For example, Chin and Osborne's (2010) study suggested that students' construction of arguments was supported by the requirement to represent the different components (a claim, data, and a warrant) of an argument diagrammatically based on Toulmin's (1958) model of argumentation. They argued that their paper-based mode of an argument diagram (an argument worksheet) as a generic outline of the structural elements of an argument assisted students in organizing their thinking visually and linguistically, comprehending the nature of their own arguments, and identifying the strengths and weaknesses of their arguments, which could offer the students a focus on their argumentation. Also, several studies have been undertaken to examine the effects of computer-supported visual tools (e.g., Belvedere) on students' argumentation. For example, students who used the Belvedere system (that is congruent with Toulmin's model of argumentation) produced significantly more argument components during group discussions than those who did not (Cho & Jonassen, 2002). Suthers and Hundhausen (2003) reported that when constructing argumentation in the Belvedere system, students who were guided by argumentation diagrams gave more consideration to evidence for supporting their claims, and after the completion of representational guidance, the diagram users had a higher quality of evidential relations in their essays than the text users.

To promote the quality of medical students' argumentation during HDR processes in PBL, an effort could be made to provide students with opportunities to learn how to construct cogent arguments, understanding an argument structure concerning HDR phases in a graphic form using an argument diagram. They should be allowed to learn and practice making arguments, including at least the three primary components of an argument (a claim, data, and a warrant), individually or in small groups, using a paper-based form or computerized argumentation tool through PBL orientations or workshops. 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 and exercise argumentation using graphical tools. Tutors' use of visual representational argumentation may develop their skills to provide students with appropriate guidance and feedback on the students' argumentation during HDR processes in PBL, which can ensure the quality of students' argumentation and HDR abilities. The following figure 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 structure of argumentation in relation to the HDR process as seen in Figure 2.4.

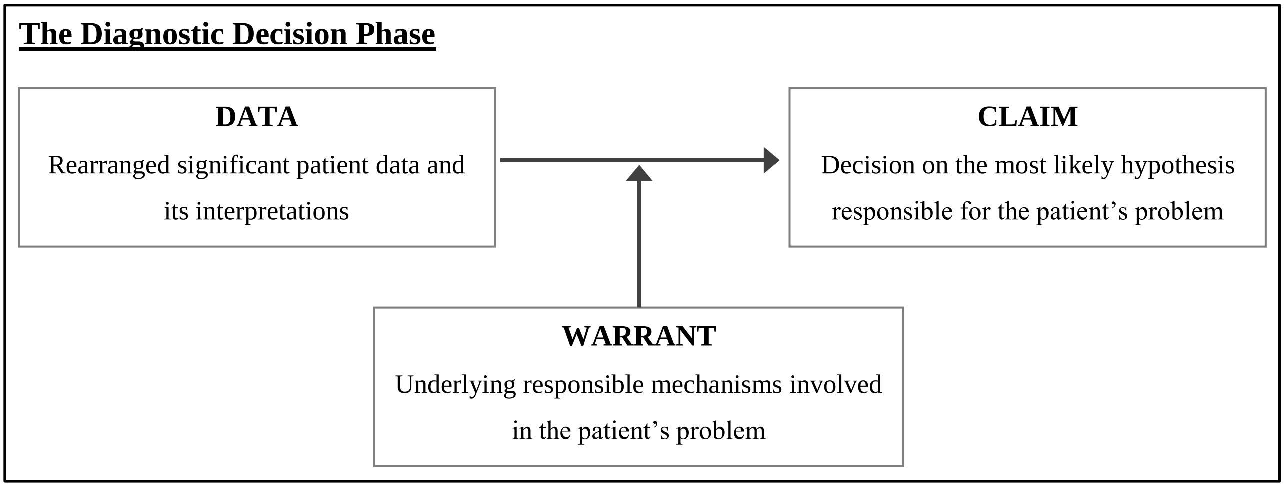

Figure 2.5. An example of an argument diagram.

Just-in-time Guidance through Questioning

Secondly, the other scaffolding strategy for students' argumentation can be questioning. Questioning is regarded as "one of the most fundamental cognitive components" (Jonassen, 2011, p. 285) that can prompt 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). Several studies have explored how to promote students' argumentation in problem solving by teachers' questioning. For example, McNeill and Pimentel's (2010) study suggested that teachers' use of open-ended questions (asking students to express their ideas and explain their reasoning) increased students' use of data (evidence) and warrants to support their claims. Higher-level questions that require deep reasoning and explanations assist students in constructing sound arguments (Hmelo & Silver, 2008; Veerman, Andriessen, & Kanselaar, 2002). That is, asking students to explain why can evaluate whether they really understood what they have learned as well as encourage them to reconsider their claims and present arguments with more justification (Jonassen, 2011). Teachers should pose questions—such as “How do you know?”, “What is your evidence for…?” and “What reasons do you have…?”—in order to enhance the quality of argumentation (Graesser, Baggett, & Williams, 1996; Larson & Keiper, 2002; Osborne, Erduran, & Simon, 2004).

To develop medical students’ HDR abilities in PBL, tutors (facilitators) should ask questions that help students provide evidence and warrants to explain their ideas about causes of a patient’s problem (Barrows, 1985; Hmelo-Silver & Barrows, 2008). According to Hmelo-Silver and Barrows’ (2008) study, facilitators’ questions about causal antecedents (e.g., “What do you know about compression leading to numbness and tingling?”, p. 61), causal consequences (e.g., “What happens when it’s, when the, when the neuron’s demyelinated?”, p. 61), and enablement (e.g., “How does involvement of veins produce numbness in the foot?”, p. 61) allowed student to engage in causal explanations for a given patient’s problem, seeking evidence and pathophysiologic principles during PBL tutorials. In terms of each phase of HDR in PBL, the following are examples of tutors’ questions that can improve the quality of students’ argumentation that involves relevant data (evidence) and scientific explanations as warrants: (1) Problem framing: tutors can stimulate students to pay attention to the patient’s initial information (data) for the initial concept of the patient’s problem (claim) by asking questions like “What information or cues seem important here?”; (2) Hypothesis generation: tutors should ask students questions, such as “What ideas do you have as to what basic mechanisms might be involved in this patient’s problem?” so that students can attempt to provide warrants that justify how the patient’s clinical manifestations (data) are related to their ideas about possible causes of the patient’s problem (claim); (3) Inquiry strategy: students should be encouraged to construct sound arguments, including appropriate data and warrants about strategies necessary to be conducted for testing hypotheses by tutors’ questions like “Why do you think that the questions (physical exams and tests) are necessary for the patient?"; (4) Data analysis and synthesis: tutors should pose questions, such as "How is the result related to basic mechanisms?" so that students can generate justifications (warrants) for their interpretations of the data obtained from inquiry strategies; (5) Diagnostic decision: tutors can guide students in explaining causal mechanisms of the patient's problem to support their diagnosis as warrants by asking "How is your primary diagnosis supported by the symptoms/findings?"; and (6) Therapeutic decision: tutors can help students make reasoned arguments, including scientific explanations, to link their chosen therapeutic strategies to the patient's problem as warrants by asking questions like "How can the treatment correct the patient's problem in terms of basic mechanisms?"

Supporting Elaboration on Structural Knowledge and Reasoning

Thirdly, another instructional strategy for encouraging students' scientific argumentation could be to engage students in elaborating on their structural knowledge. Scientific argumentation involves understandings and explanations of relationships between concepts (Duschl & Osborne, 2002; Huang, Chen, & Chen, 2009; Schwarz, Neuman, & Gil, 2003), which is related to structural knowledge defined as "the knowledge of how concepts within a domain are interrelated" (Jonassen, Beissner, & Yacci, 1993, p. 4). A tool for assisting learners in activating and representing their structural knowledge can be concept mapping—a process of structuring and organizing concepts and making a propositional statement to link concepts (Edmondson, 1994; Jonassen, 2006; Jonassen et al., 1993; Novak & Gowin, 1984; Rendas, Fonseca, & Pinto, 2006; Watson, 1989). In collaborative problem solving, the concept mapping approach can enable students to build underlying explanations that explicate or describe a phenomenon being investigated and to construct arguments that provide and justify their explanations, externalizing their knowledge (Sampson & Clark, 2008; Roth, McGinn, Woszcyna,

& Boutonne, 1999). It would also make the students' ideas visible and guide them in focusing on problem-solving processes (Toth et al., 2002). Concept mapping could be the focal point of argumentation as students draw attention to their capacity to provide evidence and explanations and evaluate others' arguments so that they can make the dynamic network of conceptual relationships perceptually salient, transfer their knowledge to the resolution of problems, and participate in collaborative knowledge building (Gonzalez et al., 2008; Osborne et al., 2004; Sampson & Clark, 2008; Roth et al., 1999).

In PBL, concept mapping can be a cognitive tool to assist medical students' clinical reasoning in structuring and organizing information and relating concepts in the basic sciences to a patient's clinical presentation (Azer, 2005; Dee, Haugen, & Kreiter, 2014; Gonzalez et al., 2008; Guerrero, 2001; Torre, Durning, & Daley, 2013; Rendas et al., 2006). That is, a picture of the cognitive analysis of a patient's problem as concept mapping can allow students to promote a mechanistic approach to a patient's problem by tracing the pathophysiologic mechanisms from the underlying causes of a disease to the clinical signs, symptoms, and findings through the use of nodes and links (Addae, Wilson, & Carrington, 2012; Azer, 2005; Dee et al., 2014; Guerrero, 2001; Rendas et al., 2006). During HDR processes in PBL, students' activity of creating a concept map as a mechanistic diagram about a patient's problem in small groups could support students' argumentation (Azer, 2005; Guerrero, 2001). For example, when students encounter a patient's problem and generate hypotheses about possible causes of the patient's problem, concept mapping can facilitate students to articulate data (evidence) and warrants for their claims (hypotheses) in terms of pathophysiological mechanisms. Following hypothesis generation, students could 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. In the phase of data analysis and synthesis, students could 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 could elaborate on the concept map, adding the significant patient data and detailed pathophysiological mechanisms to the previous concept map. The elaborated concept map that is focused around the final hypothesis would guide students in making arguments about diagnosis and therapeutic interventions for the patient's problem, which can promote the building of a comprehensive mechanistic diagram of the patient's problem. In order to achieve these goals of concept mapping in PBL, it would be of importance to introduce and show students how to construct a concept map and to provide them with opportunities to practice developing a sample concept map before starting PBL courses (Torre et al., 2013). Also, it would be helpful for tutors who are trained in mechanistic diagramming to facilitate students to engage in concept mapping by asking questions or providing feedback on their concept map during HDR processes in PBL (Azer, 2005; Guerrero, 2001; Torre et al., 2013). These efforts could encourage students to present scientific arguments through a visual representation of mechanistic sequences for a patient's case, which can enhance their HDR skills.

Conclusion

One of the important goals of PBL is to foster medical students' HDR abilities so that they can effectively resolve patients' problems they may encounter in their future clinical work (Barrows, 1985, 1994; Barrows & Tamblyn, 1980). In PBL, when medical students in small groups are presented with an authentic patient's case, they undertake a sequence of activities to solve the patient's clinical problem, employing the HDR process in interactive learning environments (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Patel et al., 1993). During HDR processes, students should be encouraged to construct sound arguments containing relevant data and warrants to substantiate their claims. Also, the HDR process involves the sequential explanations for the scientific connections between a patient's clinical presentations (e.g., symptoms and signs) and diagnoses (diseases). Students should apply basic scientific knowledge to clinical contexts in order to analyze, evaluate, and manage a patient's problem mechanistically in terms of pathophysiological mechanisms, which should be elicited in their argumentation. Thus, scientific argumentation would help students build a causal model for a patient's problem and practice scientific inquiry processes, which can support their engagement in the HDR process (Frederiksen, 1999; Hmelo-Silver & Barrows, 2008).

Constructing sound arguments and enhancing rational thoughts depend on the ability to provide justifications for one's claims, such as evidence and warrants (Lu, Chiu, & Law, 2011; von Aufschnaiter et al., 2008). Examining students' argumentation could be helpful in evaluating their reasoning and problem solving abilities. In this study, we developed a framework about the structure of argumentation, including the three essential elements of an argument (a claim, data, and a warrant), in relation to each phase of HDR adapted from Barrows' (1994) model of clinical reasoning. The framework will be used as a means of analyzing and assessing medical students' argumentation during HDR processes in PBL for further research. In addition, we discussed instructional strategies for promoting students' argumentation concerning HDR processes during PBL. This will provide guidelines for helping students engage in argumentation and enhance their HDR during PBL. Future research is also needed to investigate the effects of the recommended strategies on the quality of students' argumentation and their HDR abilities.

References

Addae, J. I., Wilson, J. I., & Carrington, C. (2012). Students' perception of a modified form of PBL using concept mapping. *Medical Teacher, 34*(11), e756–e762. doi:10.3109/0142159X.2012.689440

Albanese, M. A., & Mitchell, S. (1993). Problem based learning: A review of literature on its outcomes and implementation issues. *Academic Medicine*, *68*(1), 52–81. doi:10.1097/00001888-199301000-00012

Anderson, R. C., Nguyen-Jahiel, K., McNurlen, B., Archodidou, A., Kim, S., Reznitskaya, A., . . . Gilbert, L. (2001). The snowball phenomenon: Spread of ways of talking and ways of thinking across groups of children. *Cognition and Instruction, 19*(1), 1–46. doi:10.1207/S1532690XCI1901_1

Andrews, R. (2005). Models of argumentation in educational discourse. *Text - Interdisciplinary Journal for the Study of Discourse*, *25*(1), 107–127. doi:10.1515/text.2005.25.1.107

Azer, S. A. (2005). Facilitation of students' discussion in problem-based learning tutorials to create mechanisms: the use of five key questions. *Annals of the Academy of Medicine Singapore, 34*(8), 492–498.

Baker, M. (2003). Computer-mediated argumentative interactions for the co-elaboration of scientific notions. In J. Andriessen, M. Baker, & D. Suthers (Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments* (Vol. 1, pp. 1–25). Dordrecht: Kluwer.

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years.* New York, NY: Springer.

Barrows, H. S. (1994). *Practice-based learning: Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*, *1996*(68), 3–12. doi:10.1002/tl.37219966804

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York, NY: Springer.

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International Journal of Science Education*, *22*(8), 797–817. doi:10.1080/095006900412284

Belland, B. R. (2010). Portraits of middle school students constructing evidence-based arguments during problem-based learning: The impact of computer-based scaffolds. *Educational Technology Research and Development*, *58*(3), 285–309. doi:10.1007/s11423-009-9139-4

Belland, B., Glazewski, K., & Richardson, J. (2011). Problem-based learning and argumentation: Testing a scaffolding framework to support middle school students' creation of evidence-based arguments. *Instructional Science, 39*(5), 667–694. doi:10.1007/s11251-010-9148-z

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*(1), 26–55. doi:10.1002/sce.20286

Blair, J. A. (2011). Argumentation as rational persuasion. *Argumentation*, *26*(1), 71–81. doi:10.1007/s10503-011-9235-6

Bligh, D. (2000). *What's the point in discussion?* Portland, OR: Intellect Books.

Boshuizen, H. P., & Schmidt, H. G. (1992). On the role of biomedical knowledge in clinical reasoning by experts, intermediates and novices. *Cognitive Science, 16*(2), 153–184. doi:10.1207/s15516709cog1602_1

Brown, R., & Redmond, T. (2007). Collective argumentation and modelling mathematics practices outside the classroom. In J. Watson & K. Beswick (Eds.), *Mathematics: Essential research, essential practice: Vol. 1. The Mathematics Education Research Group of Australasia* (pp. 163–171).

Buckingham Shum, S. J., MacLean, A., Bellotti, V., & Hammond, N. V. (1997). Graphical argumentation and design cognition. *Human-Computer Interaction, 12*(3), 267–300.

Cerbin, B. (1988). *The nature and development of informal reasoning skills in college students.* Retrieved from ERIC database (ED298 805).

Chin, C., & Osborne, J. (2010). Supporting argumentation through students' questions: case studies in science classrooms. *Journal of the Learning Sciences*, *19*(2), 230–284. doi:10.1080/10508400903530036

Cho, K. L., & Jonassen, D. H. (2002). The effects of argumentation scaffolds on argumentation and problem solving. *Educational Technology Research and Development*, *50*(3), 5–22. doi:10.1007/BF02505022

Colliver, J. A. (2000). Effectiveness of problem-based learning curricula: Research and theory. *Academic Medicine*, *75*(3), 259–266. doi:10.1097/00001888-200003000-00017

Dee, F. R., Haugen, T. H., & Kreiter, C. D. (2014). New web-based applications for mechanistic case diagramming. *Medical Education Online, 19,* 24708. doi:10.3402/meo.v19.24708

Dickinson, H. D. (1998). Evidence-based decision-making: An argumentative approach. *International Journal of Medical Informatics*, *51*(2–3), 71–81. doi:10.1016/S1386-5056(98)00105-1

Diemers, A. D., van de Wiel, M. W. J., Scherpbier, A. J. J. A., Heineman, H., & Dolmans, D. H. J. M. (2011). Pre-clinical patient contacts and the application of biomedical and clinical knowledge. *Medical Education*, *45*(3), 280–288. doi:10.1111/j.1365-2923.2010.03861.x

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. doi:10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education*, *38*(1), 39–72. doi:10.1080/03057260208560187

Edmondson, K. M. (1994). Concept maps and the development of cases for problem-based learning. *Academic Medicine*, *69*(2), 108–110.

Feinstein, A. R. (1973a). An analysis of diagnostic reasoning. I. The domains and disorders of clinical macrobiology. *Yale Journal Biology Medicine*, *46*(3), 212–232.

Feinstein, A. R. (1973b). An analysis of diagnostic reasoning. II. The strategy of intermediate decisions. *Yale Journal Biology Medicine*, *46*(4), 264–283.

Frederiksen, C. H. (1986). Cognitive models and discourse analysis. In C. R. Cooper & S. Greenbaum (Eds.), *Written communication annual: Vol. 1. Studying writing: Linguistic approaches* (pp. 227–267). Beverly Hills, CA: Sage.

Frederiksen, C. H. (1999). Learning to reason through discourse in a problem-based learning group. *Discourse Processes*, *27*(2), 135–160. doi:10.1080/01638539909545055

Golanics, J. D., & Nussbaum, E. M. (2008). Enhancing online collaborative argumentation through question elaboration and goal instructions. *Journal of Computer Assisted Learning*, *24*(3), 167–180. doi:10.1111/j.1365-2729.2007.00251.x

Gonzalez, H. L., Palencia, A. P., Umana, L. A., Galindo, L., & Villafrade M., L. A. (2008). Mediated learning experience and concept maps: A pedagogical tool for achieving meaningful learning in medical physiology students. *Advances in Physiology Education*, *32*(4), 312–316. http://dx.doi.org/10.1152/advan.00021.2007

Graesser, A. C., Baggett, W., & Williams, K. (1996). Question-driven explanatory reasoning. *Applied Cognitive Psychology*, *10*(Special), 17–31. doi:10.1002/(SICI)1099-0720(199611)10:7%3C17::AID-ACP435%3E3.0.CO;2-7

Groves, M. (2007). The diagnostic process in medical practice: The role of clinical reasoning. In E. M. Vargios (Ed.), *Educational psychology research focus* (pp. 133–184). New York, NY: Nova Science Publisher.

Guerrero, A. (2001). Mechanistic case diagramming: A tool for problem-based learning. *Academic Medicine*, *76*(4), 385–389. doi:10.1097/00001888-200104000-00020

Hewson, M. G., & Ogunniyi, M. B. (2010). Argumentation-teaching as a method to introduce indigenous knowledge into science classrooms: Opportunities and challenges. *Cultural Studies of Science Education*, *6*(3), 679–692. doi:10.1007/s11422-010-9303-5

Hmelo, C. E. (1998). Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *The Journal of the Learning Sciences*, *7*(2), 173–208. doi:10.1207/s15327809jls0702_2

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction*, *26*(1), 48–94. doi:10.180/07370000701798495

Huang, C.-J., Chen, H.-X., & Chen, C.-H. (2009). Developing argumentation processing agents for computer-supported collaborative learning. *Expert Systems with Applications*, *36*(2), 2615–2624. doi:10.1016/j.eswa.2008.01.036

Hung, W. (2011). Theory to reality: A few issues in implementing problem-based learning. *Educational Technology Research and Development*, *59*(4), 529–552. doi:10.1007/s11423-011-9198-1

Jiménez-Aleixandre, M. P., & Rodriguez, A. B. (2000). "Doing the lesson" or "Doing science": Argument in high school genetics. *Science Education*, *84*(6), 757–792.

Jonassen, D. H. (2006). On the role of concepts in learning and instructional design. *Educational Technology Research & Development*, *54*(2), 177–196. doi:10.1007/s11423-006-8253-9

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments.* New York, NY: Routledge.

Jonassen, D. H., Beissner, K., & Yacci, M., (1993). *Structural knowledge: Techniques for representing, conveying, and acquiring structural knowledge.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Jonassen, D. H., & Kim, B. (2009). Arguing to learn and learning to argue: Design justifications and guidelines. *Educational Technology Research and Development*, *58*(4), 439–457. doi:10.1007/s11423-009-9143-8

Kovacs, G., & Croskerry, P. (1999). Clinical decision making: An emergency medicine perspective. *Academic Emergency Medicine*, *6*(9), 947–952. doi:10.1111/j.1553-2712.1999.tb01246.x

Kuhn, D. (1992). Thinking as argument. *Harvard Educational Review*, *62*(2), 155–178. doi:10.4324/9780203435854_chapter_7

Kuhn, D., Shaw, V., & Felton, M. (1997). Effects of dyadic interaction on argumentative reasoning. *Cognition and Instruction, 15*(3), 287–315. doi:10.1207/s1532690xci1503_1

Laughlin, P. R., & Doherty, M. A. (1967). Discussion versus memory in cooperative group concept attainment. *Journal of Educational Psychology, 58*(2), 123–128. doi:10.1037/h0024408

Larson, B. E., & Keiper, T. A. (2002). Classroom discussion and threaded electronic discussion: Learning in two arenas. *Contemporary Issues in Technology and Teacher Education [Online serial], 2*(1), 45–62.

Lu, J., Chiu, M. M., & Law, N. W. (2011). Collaborative argumentation and justifications: A statistical discourse analysis of online discussions. *Computers in Human Behavior, 27*(2), 946–955. doi:10.1016/j.chb.2010.11.021

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences, 15*(2), 153–191. doi:10.1207/s15327809jls1502_1

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education, 94*(2), 203–229. doi:10.1002/sce.20364

Means, M. L., & Voss, J. F. (1996). Who reasons well? Two studies of informal reasoning among children of different grad, ability and knowledge levels. *Cognition and Instruction, 14*(2), 139–179. doi:10.1207/s1532690xci1402_1

Miller, R. A., & Geissbuler, A. (2007). Diagnostic decision support systems. In E. S. Berner (Ed.). *Clinical decision support systems: Theory and practice* (2nd ed.) (pp. 99–125). NY: Springer.

Mochales, R., & Moens, M. F. (2011). Argumentation mining. *Artificial Intelligence and Law*, *19*(1), 1–22. doi:10.1007/s10506-010-9104-x

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education*, *21*(5), 553–576. doi:10.1080/095006999290570

Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. Cambridge: Cambridge University Press.

Nussbaum, E. M. (2011). Argumentation, dialogue theory, and probability modeling: Alternative frameworks for argumentation research in education. *Educational Psychologist*, *46*(2), 84–106. doi:10.1080/00461520.2011.558816

Nussbaum, E., & Edwards, O. V. (2011). Critical questions and argument stratagems: A framework for enhancing and analyzing students' reasoning practices. *Journal of the Learning Sciences*, *20*(3), 443–488. doi:10.1080/10508406.2011.564567

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994–1020. doi:10.1002/tea.20035

Patel, V. L., Arocha, J. F., & Zhang, J. (2005). Thinking and reasoning in medicine. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 727–750). New York, NY: Cambridge University Press.

Patel, V. L., Evans, A. E., & Groen, G. J. (1989). Biomedical knowledge and clinical reasoning. In D. A. Evans & V. L. Patel (Eds.), *Cognitive science in medicine: Biomedical modeling* (pp. 53–112). Cambridge, MA: MIT Press.

Patel, V. L., Groen, G. J., & Norman, G. R. (1993). Reasoning and instruction in medical curricula. *Cognition and Instruction, 10*(4), 335–378. doi:10.1207/s1532690xci1004_2

Patel, V. L., Groen, G. J., & Scott, H. M. (1988). Biomedical knowledge in explanations of clinical problems by medical students. *Medical Education, 22*(5), 398–406. doi:10.1111/j.1365-2923.1988.tb00774.x

Prince, K., van de Wiel, M., Scherpbier, A., van der Vleuten, C., & Boshuizen, H. (2000). A qualitative analysis of the transition from theory to practice in undergraduate training in a PBL medical school. *Advances in Health Sciences Education, 5*(2), 105–116.

Rendas, A. B., Fonseca, M., & Pinto, P. R. (2006). Toward meaningful learning in undergraduate medical education using concept maps in a PBL pathophysiology course. *Advances in Physiology Education*, *30*(1–4), 23–29. doi:10.1152/advan.00036.2005

Resnick, L. B., Salmon, M., Zeitz, C. M., Wathen, S., & Holowchak, M. (1993). Reasoning in conversation. *Cognition and Instruction, 11*(3/4), 347–364. doi:10.1207/s1532690xci1103&4_11

Reznitskaya, A., Anderson, R. C., & Kuo, L.-J. (2007). Teaching and learning argumentation. *The Elementary School Journal*, *107*(5), 449–472. doi:10.1086/518623

Reznitskaya, A., Anderson, R. C., McNurlen, B., Nguyen-Jahiel, K., Archodidou, A., & Kim, S. (2001). Influence of oral discussion on written argument. *Discourse Processes, 32*(2/3), 155–175. doi:10.1080/0163853X.2001.9651596

Roth, W.-M., McGinn, M. K., Woszcyna, C., & Boutonne, S. (1999). Differential participation during science conversations: The interaction of focal artifacts, social configurations, and physical arrangements. *Journal of the Learning Sciences*, *8*(3&4), 293–347. doi:10.1080/10508406.1999.9672073

Sackett, D. L., Rosenberg, W. C., Gray, J. M., Haynes, R. B., & Richardson, W. S. (1996). Evidence based medicine: What it is and what it isn't. *BMJ: British Medical Journal, 312*(7023), 71–72. doi:10.1136/bmj.312.7023.71

Sampson, V., & Clark, D. B. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education, 92*(3), 447–472. doi:10.1002/sce.20276

Schmidt, H. G., & de Volder, M. (Eds.). (1984). *Tutorials in problem-based learning: New directions in training for the health professions*. Assen, The Netherlands: Van Gorcum

Schwartz, P., Mennin, S., & Webb, G. (Eds.). (2001). *Problem-based learning: Case studies, experience and practice.* London, UK: Kogan page.

Schwarz, B. B., Neuman, Y., & Gil, J. (2003). Construction of collective and individual knowledge in argumentative activity. *The Journal of the Learning Sciences*, *12*(2), 219–256. doi:10.1207/S15327809JLS1202_3

Sefton, A., Gordon, J., & Field, M. (2008). Teaching clinical reasoning to medical students. In J. Higgs & M. A. Jones (Eds.), *Clinical reasoning in the health professions* (3rd ed.) (pp. 469–476). Boston, MA: Butterworth-Heinermann.

Siegel, H. (1995). Why should educators care about argumentation? *Informal Logic, 17*(2), 159–176.

Spaulding, W. B. (1969) The undergraduate medical curriculum (1969 model): McMaster University. *Canadian Medical Association Journal, 100*(14), 659–664.

Suthers, D., & Hundhausen, C. (2003). An empirical study of the effects of representational guidance on collaborative learning processes. *Journal of the Learning Sciences, 12*(2), 183–219. doi:10.1207/S15327809JLS1202_2

Szolovits, P., Patil, R. S., & Schwartz, W. B. (1988). Artificial intelligence in medical diagnosis. *Annals of Internal Medicine*, *108*(1), 80–87. doi:10.7326/0003-4819-108-1-80

Terry, W. W., & Higgs, J. J. (1993). Educational programmes to develop clinical reasoning skills. *Australian Journal of Physiotherapy*, *39*(1), 47–51. doi:10.1016/S0004-9514(14)60469-4

Torre, D. M., Durning, S. J., & Daley, B. J. (2013). Twelve tips for teaching with concept maps in medical education. *Medical Teacher, 35*(3), 201–208. doi:10.3109/0142159X.2013.759644

Toth, E. E., Suthers, D. D., & Lesgold, A. M. (2002). "Mapping to know": The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education*, *86*(2), 264–286. doi:10.1002/sce.10004

Toulmin, S. (1958). *The uses of argument.* Cambridge: Cambridge University Press.

Toulmin, S. (2003). *The uses of argument*. Cambridge: Cambridge University Press.

University of Florida 3rd Year Medicine Clerkship (2012). *Introduction to clinical reasoning and clinical decision making Doc-in-the Box (DIB)* [Data file]. Retrieved from http://clerkship.medicine.ufl.edu/files/2012/07/Doc-in-the-Box-Handout-7-17-12.pdf

van Berkel, H. J. M., & Dolmans, D. H. J. M. (2006). The influence of tutoring competencies on problems, group functioning and student achievement in problem-based learning. *Medical Education, 40*(8), 730–736. doi:10.1111/j.1365-2929.2006.02530.x

van de Wiel, M. J., Boshuizen, H. A., & Schmidt, H. G. (2000). Knowledge restructuring in expertise development: Evidence from pathophysiological representations of clinical cases by students and physicians. *European Journal of Cognitive Psychology, 12*(3), 323–355. doi:10.1080/095414400501145543 van Eemeren, F. H., Grootendorst, R., Henkemans, F. S., Blair, J. A., Johnson, R. H., Krabbe, E. C. W., . . . Zarefsky, D. (1996). *Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments.* Mahwah, NJ: Lawrence Erlbaum Associates.

Veerman, A., Andriessen, J., & Kanselaar, G. (2002). Collaborative argumentation in academic education. *Instructional Science, 30*(3), 155–186.

von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching, 45*(1), 101–131. doi:10.1002/tea.20213

Walton, D. (2007). *Dialog theory for critical argumentation.* Philadelphia, PA: John Benjamins.

Watson, G. R. (1989). What is... Concept Mapping? *Medical Teacher, 11*(3/4), 265–269. doi:10.3109/01421598909146411

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

Woods, N. N., Brooks, L. R., & Norman, G. R. (2005). The value of basic science in clinical diagnosis: Creating coherence among signs and symptoms. *Medical Education, 39*(1), 107–112. doi:10.1111/j.1365-2929.2004.02036.x

Woods, N. N., Brooks, L. R., & Norman, G. R. (2007). The role of biomedical knowledge in diagnosis of difficult clinical cases. *Advances in Health Sciences Education, 12*(4), 417–426. doi:10.1007/s10459-006-9054-y

Zeidler, D. L. (1997). The central role of fallacious thinking in science education. *Science Education*, *81*(4), 483–496. doi:10.1002/(SICI)1098-237X(199707)81:4<483::AID-SCE7>3.0.CO;2-8

CHAPTER 3

ASSESSING KOREAN MEDICAL STUDENTS' ARGUMENTATION DURING HYPOTHETICO-DEDUCTIVE REASONING (HDR) IN PROBLEM-BASED LEARNING (PBL)[2]

[2] Ju, H., Choi, I., & Yoon, B. To be submitted to *Korean Journal of Medical Education*.

Abstract

Hypothetico-deductive reasoning (HDR) is one of essential learning activities as well as learning outcomes in problem-based learning (PBL). It is important for medical students to engage in the HDR process through argumentation during PBL. This study aimed to analyze and assess medical students' argumentation during HDR processes in PBL. Two small groups of seven to eight Korean medical students participated in this study. The students' arguments constructed during the HDR processes were analyzed using a coding scheme that included four types of argumentation (incomplete, claim only, claim with data, and claim with data and warrant). The results of this study revealed that the students often omitted data or did not provide warrants to connect their claims and data. The results suggest that pedagogical interventions are needed to enhance the quality of students' arguments during HDR processes in PBL.

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

Introduction

Clinical reasoning refers to a "cognitive process that is necessary to evaluate and manage a patient's medical problems" (Barrows & Tamblyn, 1980, p. 19) and is the most essential skill that a physician must possess (Croskerry, 2009). Medical students need to develop clinical reasoning skills so that they can engage in accurate and timely problem solving when faced with clinical problems in their future professional lives (Groves, 2012; Kempainen, Migeon, & Wolf, 2003). Many medical schools have adopted a problem-based learning (PBL) method, a learner-centered educational approach in which learners investigate, explain, and resolve complex and meaningful problems through small group discussions (Barrows & Tamblyn, 1980; Hmelo-Silver, 2004) with the educational goal of enhancing their students' hypothetico-deductive reasoning (HDR) skills to help students develop diagnostic reasoning abilities and deepen their knowledge in their early medical training (Groves, 2007; Patel, Arocha, & Zhang, 2005).

In PBL, medical students are first presented with a patient's problem, which is real-world, complex, and ill-structured; the students evaluate the problem by generating multiple hypotheses based on cues or information given by the patient and then test the hypotheses using inquiry strategies and clinical skills; and finally, they make a diagnostic and/or therapeutic decision (Barrows, 1985, 1994; Barrows & Tamblyn, 1980). Throughout the PBL process, except during self-directed study time, students are encouraged to engage in argumentation by constructing and exchanging their ideas and providing a reasoned argument that supports their ideas generated to solve the given problems, and a tutor should play a role in facilitating student argumentation (Hmelo-Silver & Barrows, 2008; Savery & Duffy, 2001). In other words, the students' argumentation during PBL small group discussions allows them to apply basic scientific knowledge to clinical contexts, take a coherent approach to diagnostic inquiry, and construct collaborative knowledge that involves causal explanations of a patient problem (Frederiksen, 1999; Hmelo-Silver & Barrows, 2008), which can reflect the HDR process.

If hypothetico-deductive reasoning (HDR) is one of the essential learning activities as well as learning outcomes of PBL, it is critical to find ways to diagnose and enhance the students' argumentation exchanged during their small group discussions. Although there are several studies that have examined the types of verbal interactions (e.g., statements and questions) among medical students or between students and tutors during PBL discussion sessions (e.g., Visschers-Pleijers et al., 2006), there are very few studies that have focused on medical students' argumentation with regard to the process of HDR during PBL.

A majority of medical schools in South Korea have implemented PBL as part of their undergraduate curricula since the late 1990s (Kim et al., 2004; Yeo & Chang, 2016). However, Korean medical students and instructors (tutors) have experienced challenges during their PBL sessions with cultures (e.g., large power distance, high uncertainty avoidance, etc.) different from cultures that may boost PBL (e.g., small power distance, low uncertainty avoidance, etc.) (see Ju, Choi, Rhee, & Lee, in press). For example, the Korean medical students were concerned about their lack of prior knowledge for supporting their ideas and tended to leap to a certain diagnosis of an illness, overlooking basic mechanisms involved in a patient's problem during PBL group discussions (Ju et al., in press), which might have an impact on the quality of their argumentation during HDR processes in PBL. In an attempt to promote Korean medical students' argumentation in PBL, empirical research for exploring how Korean medical students actually engage in argumentation during PBL through analyses of students' discussions is needed.

Thus, the purposes of this study are (1) to develop an analytical framework that allows for the examination of medical students' argumentation while exercising HDR in PBL, and (2) to analyze Korean medical students' argumentation during a small group's HDR. In particular, this study focuses on understanding the quality and quantity of arguments generated in each phase of HDR. It is expected that the findings of this study will provide insights into developing effective strategies to foster medical students' argumentation skills in PBL, which would enhance their HDR skills.

An Analytical Framework for Examining Argumentation in HDR

Argumentation involves reasoning (Cerbin, 1988; Jiménez-Aleixandre & Rodriguez, 2000; Jonassen, 2011; Kuhn, 1992; van Eemeren et al., 1996), and the quality of argumentation depends on the ability to provide justifications (evidence and explanations) for supporting claims (Lu, Chiu, & Law, 2011). Argumentation theory can provide a theoretical framework for determining the structure of arguments as well as for analyzing and evaluating students' thinking and reasoning (Bligh, 2000; Driver, Newton, & Osborne, 2000; Jonassen, 2011; Nussbaum, 2011; Siegel, 1995). Toulmin's model (1958, 2003) is regarded as the most seminal argumentation model (Andrews, 2005; Jiménez-Aleixandre & Rodriguez, 2000; Jonassen, 2011; Nussbaum, 2011). Toulmin's model (1958, 2003) emphasizes three primary components of an argument: (1) a claim: an expression of a position that is advanced in an argument; (2) data: factual information that favors the acceptance of a claim; and (3) a warrant: a rule of inference that justifies the transition from the data to a claim. For valid arguments, the importance of warrants that can play a critical role in making claims appropriate and legitimate is emphasized (Toulmin, 1958, 2003). In addition, Toulmin (1958, 2003) suggested that more complex arguments can include three additional components: (1) a backing: factual information to provide a rationale for a warrant; (2) a rebuttal: a statement that would weaken or invalidate the claim; and (3) a qualifier: a word or phrase to express limited certainty of the claim (e.g., 'perhaps' and 'probably'). Some components may be absent or left implicit in an argument (Nussbaum, 2011; Toulmin, 1958, 2003). Since constructing sound arguments basically depends on the ability to provide data and warrants for one's claims (Toulmin, 1958, 2003; von Aufschnaiter, Erduran, Osborne, & Simon, 2008), this study will focus on the three primary components—a claim, data, and a warrant—of the six components for argumentation proposed by Toulmin (1958, 2003).

PBL involves a small group activity in which students' argumentation guides what is learned. In PBL, after medical students in groups are presented with a patient's problem, they are encouraged to engage in the HDR process, constructing reasoned arguments for medical problem solving (Frederiksen, 1999; Hmelo-Silver & Barrows, 2008). Evaluating and analyzing the students' argumentation during PBL will provide insight into understanding and examining students' HDR processes.

Thus, in order to develop an analytical framework for assessing students' argumentation within the HDR process, the structure of argumentation based on the three basic components of Toulmin's (1958, 2003) argumentation model (a claim, data, and a warrant) is integrated into the six phases of the HDR process.

The Argumentation Structure Contextualized in HDR

The general process of physicians' HDR when confronted with a patient's problem can be divided into the following phases: problem framing, hypothesis generation, inquiry strategy, data analysis/synthesis, and diagnostic/ therapeutic decision(s) (Barrows, 1985, 1994; Barrows & Tamblyn, 1980). Although HDR generally consists of five or six phases, the process is not linear but iterative (Barrows & Tamblyn, 1980; Terry & Higgs, 1993). The HDR process, which can provide a useful procedural guideline for students who have insufficient domain knowledge and clinical experiences to solve a patient's problem, is incorporated in the PBL approach (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Elstein, 1995; Sefton, Gordon, & Field, 2008); medical students are encouraged to practice and develop the HDR process through argumentation during PBL.

The following discusses each phase of HDR adapted from Barrows' (1994) model of clinical reasoning and the contextualized argumentation structure, including the three primary components of an argument (a claim, data, and a warrant) based on Toulmin's (1958, 2003) model, for each HDR phase during PBL (Chapter 2, see Table 3.1):

(1) Problem framing: Students perceive a variety of information or cues (e.g., appearance, age, or personal circumstances) from a patient and form an initial idea of a patient's problem as a synthesis of the perceived initial information or cues.

In terms of argumentation for this phase, the students' claims would be an initial idea of a patient's problem from the importantly perceived patient information or cues. As data to support the claim, the students can provide the initial information or cues that were observed or heard in their initial encounter with the patient. As warrants to justify their claims and data, the students may explain why the patient information or cues are considered important.

(2) Hypothesis generation: Based on the initial idea of the patient's problem, the students generate multiple hypotheses to explain the patient's problem. The students should be encouraged to develop hypotheses of pathological or physiological mechanisms rather than clinical diagnostic entities. As the inquiry continues, the students may modify their hypotheses, or they may create new hypotheses.

For argumentation in this phase, the students' claims would be basic mechanisms (anatomy, biochemistry, physiology, pathogenesis, etc.) or disease entities responsible for the patient's problem. Data (evidence) for the claims can be the identified patient information or cues recognized as important patient data. Students may use their knowledge of pathophysiological mechanisms to connect the claim and data (evidence) as warrants.

Table 3.1

An Analytical Framework for Argumentation in the Hypothetico-Deductive Reasoning Process

	Argumentation Structure		
HDR Process	Data	Warrant	Claim
Problem Framing	Identified information or cues	Explanation why the identified information or cues are important	Initial concept of the patient's problem from the identified information or cues considered important
Hypothesis Generation	Identified information or cues recognized as important data	Pathophysiological mechanisms involved in the patient's problem	Basic mechanisms (anatomy, biochemistry, physiology, etc.) or disease entities that could be responsible for the patient's problem
Inquiry Strategy	Patient's information or cues organized by generated hypotheses	Basic mechanisms underlying hypotheses entertained; information that the inquiry actions will produce	Actions or decisions on what information would be necessary
Data Analysis/ Synthesis	Data acquired from inquiry strategies	Basic mechanisms at the appropriate level	Interpretation on significant patient data that relates to the hypotheses considered
Diagnostic Decision	Rearranged significant patient data and its interpretations	Underlying responsible mechanisms involved in the patient's problem; diagnostic criteria for the most likely disease	Decision on the most likely hypothesis(es) responsible for the patient's problem
Therapeutic Decision	Diagnostic decision(s) with relevant patient's data	Basic mechanisms relating to the therapeutic interventions; research into the therapeutic efficacy of the chosen treatments	Decision on the approach to the treatment of the patient's problem

Note. Adapted from Chapter 2.

(3) Inquiry strategy: For testing hypotheses, the students should determine what inquiry strategies or actions should be used to obtain more information. They may carry out the actions,

such as history taking and physical examinations, employing appropriate clinical skills (e.g., communication skills or psychomotor skills).

As the students engage in argumentation during this process, the students may make claims about decisions or actions (questions, physical examination items, and laboratory or diagnostic tests) that would be important in hypothesis testing. Data for the claims can be the patient's data involved in the generated hypotheses. As warrants, the students may use their knowledge of the basic mechanisms related to the hypotheses or describe what information that the inquiry actions will provide for validating the hypotheses considered.

(4) Data analysis and synthesis: The students analyze data acquired from the inquiry strategy to determine whether the data strengthens or weakens any of the hypotheses considered. They synthesize significant data obtained from the data analysis.

In terms of argumentation, the students' claims may be data interpretations as to whether the obtained patient's data is significant with regard to the hypotheses entertained. The students would use the patient's data obtained from inquiry strategies (e.g., the results of laboratory tests) as evidence to support their claims. For warrants, the students may explain how the test results help to define significant data for the hypotheses in terms of basic mechanisms at the appropriate level (organ, tissue, cellular, or molecular).

(5) Diagnostic decision: After deciding that no more helpful data can be obtained at the time, the students come to a decision about the most likely clinical diagnosis(es) based on the underlying mechanisms involved in the patient's problem.

With regard to argumentation during this phase, the students' claims may be a decision(s) about the most likely hypothesis(es) entertained. Data (evidence) of their claims may be significant patient data and its interpretations rearranged through the analysis and synthesis of the data. As warrants, the students would provide explanations of underlying mechanisms responsible for the patient's problem or diagnostic criteria for a certain disease considered most likely based on the patient's data.

(6) Therapeutic decision: The students also decide what therapeutic strategies would be necessary to improve the patient's condition, such as medication or surgery. In this phase, therapeutic decisions should be made in terms of basic mechanisms (Barrows, 1985).

For argumentation during this phase, the students' claims may be decisions on approaches to the treatment of the patient's problem. The students would state their diagnostic decision(s) using relevant patient data as evidence for their claims. To justify their claims and data, they may describe basic mechanisms related to therapeutic interventions or use the results of research on the therapeutic efficacy of the chosen treatment in terms of evidence-based medicine (Dickinson, 1998; Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996).

Methods

Research Site and Participants

Site. This study was conducted at one of the leading medical schools in South Korea. At the medical school, a two-year premedical and four-year (two-year preclinical and two-year clinical) medical education system has been implemented. The school's preclinical students took a total of fourteen organ system block courses (e.g., nervous system) for two years; each organ system block course included three- to four-week lectures subsequent to a one-week PBL course; and the PBL method comprised one-fourth of its first- and second-year preclinical curricula (Ju et al., in press). One hundred first-year preclinical students and 94 second-year preclinical students participated in the PBL courses during the fall semester of 2014.

PBL setting. Barrow's model of PBL (Barrows, 1985, 1994; Barrows & Tamblyn, 1980) has been employed at this school, and the PBL approach used in the preclinical years encourages the use of hypothetico-deductive reasoning. For each PBL course, a small group of seven to eight students had two-hour discussion sessions guided by a tutor three times a week (Monday, Wednesday, and Friday) to work on a clinical case using a standardized patient (SP) as demonstrated in Figure 3.1.

Weekly Schedule	Clinical Reasoning Process (Barrows, 1985, 1994)	Learning Artifacts
1st Session (Monday, 2 hours)	Taking a chief complaint from a standardized patient (SP)	• Learning goals • An initial concept map
	Perceiving cues	
	Generating multiple hypotheses	
	Determining questions about the medical history (Hx) to be asked	
	Interviewing the SP	
	Determining the physical exam (PEx) items to be conducted	
	Conducting the PEx of the SP	
	Analyzing data obtained from the Hx and PEx	
	Synthesizing the significant data from the Hx and PEx	
	Refining, ranking, or ruling out the hypotheses	
2nd Session (Wednesday, 2 hours)	Determining the diagnostic test items to be ordered	• Learning goals • A revised concept map
	Analyzing the results of the tests	
	Synthesizing the significant data from the Hx, PEx, and tests	
	Making (a) diagnostic decision(s)	
	Making (a) therapeutic decision(s) (Principles of management)	
3rd Session (Friday, 2 hours)	Making (a) therapeutic decision(s) (Acute and long-term management)	• Learning goals

Figure 3.1. The problem-based learning process used in the medical school.

During the time of this study, the PBL course was concerned with the cardiovascular system. The clinical case for the PBL course represented an acute myocardial infarction (MI) with a standardized patient (SP) complaining of chest pain and dyspnea. During the first session, the students in a group formulated a patient's problem with important information or cues obtained from a standardized patient, generated multiple hypotheses, conducted inquiry strategies (e.g., history taking and physical examinations), analyzed and synthesized the patient's data, and then modified and ranked their hypotheses. Throughout the first session, the group was asked to develop an initial concept map representing categories of ideas including diseases or mechanisms that could be responsible for the patient's problem based on the group's brainstorming. A standardized patient was not used during the second and third sessions. The second session involved clinical reasoning processes to further the inquiry strategy, such as diagnostic tests, data analysis and synthesis, diagnostic decisions, and therapeutic decisions (principles of managements). The group was required to produce a revised concept map representing the pathophysiological mechanisms of the possible causal diseases. In the third session, students discussed acute and long-term management plans for improving the patient's condition. Throughout the three sessions, students identified and listed learning goals (needs), which required additional study.

Participants. The participants for this study were 15 first-year preclinical students who had participated in the PBL course on the cardiovascular system. The students were selected through a criterion-based case selection strategy (Patton, 2015). Initially, two PBL groups out of the 15 groups of first-year preclinical students were selected based on two criteria: a PBL group will be facilitated by a tutor who (1) has a great deal of experience with PBL tutoring and (2) would be most likely to participate in PBL tutoring for the PBL course on the cardiovascular system during a future study. After selecting two groups that met these criteria, students from the groups were informed about this study and consented to be part of it.

Table 3.2

Participants

	The number of students		Total
	Male	Female	
Group 1	5	3	8
Group 2	5	2	7
Total	10	5	15

Data Collection

A set of three PBL discussion sessions guided by a tutor for each of the two groups of seven to eight first-year preclinical students was audio-recorded. The data consisted of about twelve hours of audio-recordings for the two groups' PBL discussion sessions; each session lasted for about two hours. The audio-recorded discussions of the two groups were transcribed verbatim.

Data Analysis

Unit of analysis. The transcripts of the two groups' discussions were analyzed. The unit of analysis was one argument verbally expressed by one person, including at least one of the three primary components of an argument. One argument dealt with one topic that was related to clinical reasoning for the patient's problem and was in a statement form, not a question form. Analyses of the data included examining the numbers and types of arguments elicited.

Coding scheme. Before analyzing each argument as a basic unit of analysis, meaningful segments of successive arguments exchanged among the participants of each small group were identified and categorized according to Barrows' (1994) HDR phases. The coding categories included problem framing, hypothesis generation, inquiry strategy, data analysis/synthesis, diagnostic decision, and therapeutic decision. For the analysis of each argument, the argument was analyzed according to the three essential elements of an argument (a claim, data, and a warrant) based on the analytical framework for argumentation in the HDR process (see Table 3.1). Then each argument was categorized by a coding scheme of the following four types of arguments (see Table 3.3). Type 0 indicated an incomplete argument consisting of data or warrant(s) without a claim; for example, students mentioned factual information, such as a patient's clinical data (e.g., blood test results) or knowledge acquired from their textbook, without mentioning how the information is related to their own ideas on the issue being discussed, or they provided data or warrants for claims raised by other students but did not explicitly indicate the particular claims; Type 1 consisted of only a claim without justifications (data or warrants); Type 2 had an argument consisting of a claim with data but no warrant(s); and Type 3 contained a claim with data and warrant(s) and was regarded as the most sophisticated and complete form of an argument among the four types of arguments.

Table 3.3

Coding Scheme

Type of Argument	Code	Description	Example
0	Incomplete	Data or warrant(s) without claim	The patient has high levels of BUN (Data).
1	Claim	Claim without data and warrant(s)	I think angina is likely (Claim).
2	Claim-Data	Claim with data but no warrant(s)	Because the patient has low blood pressure (Data), he may have bleeding (Claim).
3	Claim-Data-Warrant	Claim with data and warrant(s)	It is necessary to provide beta blockers or nitrates (Claim) for the patient with acute MI [myocardial infarction] (Data). The medications can lower his blood pressure. A decrease in BP [blood pressure] leads to a decrease in oxygen demand, which in turn relieves ischemic chest pain (Warrant).

Inter-rater reliability. Initially, the first author reviewed the entire transcripts of the two groups' discussions and divided them into meaningful segments according to the HDR phases. As a result, a total of 55 discussion segments were identified—26 segments in Group 1's discussions and 29 segments in Group 2's discussions respectively—and each of the segments was coded as one of the six HDR phases. Then the first author identified viable arguments in each segment according to the definition of one argument used for this study (see the "Unit of analysis" section), and a total of 561 arguments were identified for further analysis.

For the purpose of rater-training, a total of 17 segments (31% of the total segments), holding a total of 180 arguments (about 35% of the total arguments), across the three discussion sessions from one group (Group 1) were selected considering an appropriate distribution of the selected segments the six phases of HDR. The first author (an education expert) coded each of the arguments into one of the four types of arguments using the coding scheme. Then the third author (a medical educator) reviewed the first author's codes for the argument type and for the segment type (HDR phases) respectively. The rate of agreement between the two reviewers was 98% for the coding of the argument type and 100% for the coding of the HDR phase respectively.

Once an acceptable level of agreement between the two reviewers was confirmed, all of the remaining data (381 arguments in 38 segments) were coded by the first author. To obtain inter-rater reliability of the first author's coding, a total of 24 segments (63% of the total remaining segments) were randomly selected, which included 195 arguments (51% of the total remaining arguments), and these were coded by the third author independently. Cohen's (1960) kappa was calculated for the coding of the argument type, and a high level of inter-rater reliability (k = .88) was obtained (Landis & Koch, 1977). With regard to the coding of the segments for the HDR phases, 100% of agreement between the two reviewers for the selected 24 segments was obtained.

Analysis. To analyze the students' argumentation during group discussions, a quantitative analysis was conducted. To investigate the frequency of the occurrences of the four types of arguments during group discussions, the mean frequency was calculated for each category in the coding scheme across the two small groups. Furthermore, the mean frequency of each type of argument constructed during each HDR phase was computed across the two groups.

We also counted the number of words in each type of argument, which can provide a supplemental understanding of students' engagement in generating their arguments.

Results and Discussion

Frequency of the Different Types of Student Arguments during Group Discussion

The mean frequency of each of the four types of arguments students constructed across the two small groups was calculated. We found that arguments consisting of only claims (Type 1 arguments) were generated most often (*mean of frequency* = 120.5, 43%) among the four types of arguments, whereas the least common were arguments comprising claims with data and warrants (Type 3 arguments, *mean of frequency* = 24.5, 8.7%). Arguments including claims and data (Type 2 arguments) had the second highest frequency (68.5, 24.4%). The results can be a furtherance of those studies reporting that claims were generated more frequently than evidence or warrants by high school students during scientific inquiry processes (Jiménez-Aleixandre & Rodriguez, 2000; McNeill & Krajcik, 2007; McNeill, Lizotte, Krajcik, & Marx, 2006). We observed a number of incomplete arguments that did not include explicit claims (*mean of frequency* = 67, 23.9%), which should be interpreted with the limitation of our data analysis in which we only included verbally expressed claims. As a result of calculating the word count per argument for each type of argument, Type 3 arguments had the highest word count per argument (39.1), and Type 1 arguments had the lowest word count per argument (5.4). This indicates that more words were used to provide data and warrants for claims rather than for generating only claims. The frequency and word count of the different types of arguments constructed for the two groups are presented in Table 3.4.

Table 3.4

Arguments Generated by Each Group during Group Discussion

Type of Argument	Group 1		Group 2		Group Average		
	Frequency of argument	Word count	Frequency of argument	Word count	Frequency of argument (%)	Word count (%)	Word count per argument
Type 0: Incomplete	40	221	94	594	67 (23.9)	407.5 (12.9)	6.1
Type 1: Claim Only	94	563	147	735	120.5 (43)	649 (20.5)	5.4
Type 2: Claim-Data	64	1221	73	1087	68.5 (24.4)	1154 (36.4)	16.8
Type 3: Claim-Data-Warrant	25	1229	24	688	24.5 (8.7)	958.5 (30.2)	39.1
Total	223	3234	338	3104	280.5 (100)	3169 (100)	11.3

The Frequency of Each Type of Argumentation per Group during Each HDR Phase

The frequency of each type of argument generated per group was calculated and analyzed according to each HDR phase as shown in Table 3.5.

Table 3.5

The Frequency of Arguments per Group during Each Phase of Hypothetico-Deductive Reasoning

	Hypothetico-Deductive Reasoning Phase													
	Problem Framing		Hypothesis Generation		Inquiry Strategy		Data Analysis/ Synthesis		Diagnostic Decision		Therapeutic Decision		Total	
Type of Argument	Frequency of argument (%[a])	Word count (%[a])	Frequency of argument (%[a])	Word count (%[a])	Frequency of argument (%[a])	Word count (%[a])	Frequency of argument (%[a])	Word count (%[a])	Frequency of argument (%[a])	Word count (%[a])	Frequency of argument (%[a])	Word count (%[a])	Frequency of argument (%[a])	Word count (%[a])
Type 0: Incomplete	1.5 (33.3)	6 (27.3)	5.5 (7.3)	34 (6.6)	0 (0)	0 (0)	53 (71.1)	277.5 (39.3)	0 (0)	0 (0)	7 (9.7)	90 (6.1)	67 (23.9)	407.5 (12.9)
Type 1: Claim Only	2.5 (55.6)	4 (18.2)	43.5 (58)	161 (31.3)	45.5 (87.5)	224 (62.8)	5.5 (7.4)	33 (4.7)	0 (0)	0 (0)	23.5 (32.6)	227 (15.3)	120.5 (43)	649 (20.5)
Type 2: Claim-Data	0.5 (11.1)	12 (54.5)	22.5 (30)	241.5 (46.9)	5.5 (10.6)	100 (28.1)	9 (12.1)	163.5 (23.1)	1 (40)	45.5 (53.5)	30 (41.7)	591.5 (39.9)	68.5 (24.4)	1154 (36.4)
Type 3: Claim-Data-Warrant	0 (0)	0 (0)	3.5 (4.7)	78.5 (15.2)	1 (1.9)	32.5 (9.1)	7 (9.4)	233 (33)	1.5 (60)	39.5 (46.5)	11.5 (16)	575 (38.8)	24.5 (8.7)	958.5 (30.2)
Total (%[b])	4.5 (1.6)	22 (0.7)	75 (26.7)	515 (16.4)	52 (18.5)	356.5 (11.2)	74.5 (26.6)	707 (22.3)	2.5 (0.9)	85 (2.7)	72 (25.7)	1483.5 (46.8)	280.5 (100)	3169 (100)

Note. %[a] = % within the HDR phase; %[b] = % of the Total.

Problem framing. After the first encounter with a standardized patient (SP), students started to discuss what information or cues were presented by the SP, and they mentioned factual information that they heard or observed, which indicated incomplete (Type 0) arguments (*frequency* = 1.5, 33.3%). Then, the students discussed what information or cues would be important to form an initial concept of a patient's problem and generated only claims (Type 1 arguments, *frequency* = 2.5, 55.6%). For example, when the chairperson in Group 2 asked other group members to discuss the patient's chief complaints, one student answered, "It is chest pain (Claim)," and then, the chairperson asked again, "Is there anything else?" and another student answered, "It is shortness of breath (Claim)." While formulating the patient's problems, only one student made a claim with data (a Type 2 argument), using the patient's important cues and information (*frequency* = 0.5, 11.1%). An example of a Type 2 argument is "I think the patient seems to be an emergent patient (Claim), because he has two symptoms, chest pain and dyspnea, and has difficulty sitting (Data)." The word count of the Type 1 arguments (*word count* = 4, 18.2%) was lower than that of the Type 2 arguments (*word count* = 12, 54.5%). In this phase, the students generated only 4.5 arguments per group (1.6%) out of the total arguments (*mean of frequency* = 280.5) constructed during all HDR phases. This low frequency of arguments can be explained by the actual time spent on this phase, about three minutes per group, determining the patient's chief complaints based on their initial interview with the SP. We observed that the students obtained very limited information from the SP during the initial interview. This may also be why there were a small number of arguments produced during this phase.

Hypothesis generation. In this phase, the students engaged in generating multiple hypotheses to explain the patient's problem. A total of 75 arguments were constructed during this phase, which was the largest frequency among the different HDR phases. This result explains that this phase involved the creative process of problem solving (Barrows, 1985, 1994; Barrows & Tamblyn, 1980) in which the students produced many ideas that might be causes for the patient's problem by brainstorming. In addition, the students spent a large amount of time developing initial hypotheses after problem framing as well as modifying the ranking of the hypotheses or considering new hypotheses after analyses and syntheses of newly obtained data from inquiry strategies. Thus, the students' arguments constructed during the hypothesis generation phase were analyzed according to two stages: initial hypothesis generation and hypothesis regeneration (see Table 3.6).

Initial hypothesis generation. Following the problem framing phase, the students generated as many initial ideas as possible that might be responsible for the patient's problem with the limited information provided by the SP. In the initial hypothesis generation, most students brainstormed names of diseases rather than basic mechanisms as hypotheses without providing data or warrants (*frequency* = 38, 78.4%), such as "I think MI [myocardial infarction]" and "Angina is likely," which indicated Type 1 arguments. Type 1 arguments had the highest word count (133, 57.5%) among the four types of arguments made during this stage. The number of Type 2 arguments (claims with data) was 10 (20.6%). When several students provided data for their hypotheses, they used the patient's chief complaints (e.g., chest pain and dyspnea). For example, "The patient has chest pain (Data), so he may have angina (Claim)." An argument consisting of a claim, data and a warrant (a Type 3 argument) accounted for 1% of the arguments (*frequency* = 0.5) generated during the initial hypothesis generation. An example of a Type 3 argument is "The patient complains of dyspnea (Data). He may have an embolism in a pulmonary artery (Claim), which can inhibit blood circulation in the lungs, which results in dyspnea (Warrant)."

Hypothesis regeneration. After the students obtained additional information from the patient through an interview, physical exams, or tests (e.g., blood tests and X-rays), they modified and ranked their initial hypotheses or regenerated hypotheses. While ruling in and out hypotheses, the students presented incomplete arguments (*frequency* = 5.5, 20.8%), addressing the patient's data acquired from inquiry strategies without explicit claims (e.g., His heart rate is irregular). Arguments constructed during this stage mostly consisted of Type 2 arguments (claims with data) (*frequency* = 12.5, 47.2%), while Type 1 arguments (only claims) accounted for about 20.8% (*frequency* = 5.5) of the total (*frequency* = 26.5). Compared to the initial hypothesis generation stage, although Type 3 arguments were generated more in this stage, the number of Type 3 arguments was the lowest (*frequency* = 3, 11.3%) among the four types of arguments made during this stage. This indicates that the students developed hypotheses, focusing more on identifying diseases (conclusions) rather than on explaining basic pathophysiological mechanisms (Ju et al., in press). To enhance students' learning experiences with PBL, the students should be encouraged to generate hypotheses articulating basic pathophysiological mechanisms (Barrows, 1985); thus, the students need to have guidance for developing their hypotheses and incorporating biomedical knowledge. The following is an example of a Type 3 argument constructed during hypothesis regeneration: "I think that atherosclerosis or ischemia is a more likely hypothesis among our hypotheses (Claim). The patient has suffered from hypertension and hyperlipidemia for ten years (Data). Hypertension and hyperlipidemia cause atherosclerosis in coronary arteries that supply blood to the heart or narrowing blood vessels, which results in ischemia, which may cause chest pain (Warrant)." For the word count in the hypothesis regeneration, Type 2 arguments had the highest word count (158, 55.7%), and Type 1 arguments had the lowest word count (28, 9.9%).

Table 3.6

Types of Arguments during the Hypothesis Generation Phase

	Initial Hypothesis Generation		Hypothesis Regeneration		Total	
Type of Argument	Frequency of argument (%[a])	Word count (%[a])	Frequency of argument (%[a])	Word count (%[a])	Frequency of argument (%[a])	Word count (%[a])
Type 0: Incomplete	0 (0)	0 (0)	5.5 (20.8)	34 (12)	5.5 (7.3)	34 (6.6)
Type 1: Claim Only	38 (78.4)	133 (57.5)	5.5 (20.8)	28 (9.9)	43.5 (58)	161 (31.3)
Type 2: Claim-Data	10 (20.6)	83.5 (36.1)	12.5 (47.2)	158 (55.7)	22.5 (30)	241.5 (46.9)
Type 3: Claim-Data-Warrant	0.5 (1)	15 (6.5)	3 (11.3)	63.5 (22.4)	3.5 (4.7)	78.5 (15.2)
Total (%[b])	48.5 (64.7)	231.5 (45)	26.5 (35.3)	283.5 (55)	75 (100)	515 (100)

Note. %[a] = % within the HDR phase; %[b] = % of the Total.

Inquiry strategy. The primary discussion in this phase focused on determining what inquiry strategies or further information would be necessary and important for hypothesis testing. Type 1 arguments (only claims) accounted for 87.5% (*frequency* = 45.5) of the total number of arguments (52) generated during this phase and included the highest word count (224, 62.8%) of the total word count (356.5). For example, students said, “We should perform a chest examination” or “An echocardiography test would be necessary.” This result indicates that most students seemed to generate routine action items (e.g., following a list of basic tests, such as blood tests and X-rays) without providing specific reasons about why the particular inquiry strategies would be necessary for the given case. Arguments consisting of claims and data (Type 2 arguments) made up 10.6% (*frequency* = 5.5) of the total arguments generated (*frequency* = 52) and included about 28% (*word count* = 100) of the total word count (356.5). An example of a

Type 2 argument is “It would be good to order an EKG [electrocardiogram] (Claim), because the patient may have heart disease (Data).” One argument, a claim coupled with data and a warrant (a Type 3 argument), was produced during this phase (1.9%), and it had a total of 32.5 words (9.1%). An example of a Type 3 argument is “I think that a cardiac enzyme test would be necessary (Claim). Elevated cardiac enzyme levels, such as CK-MB or troponin levels, can occur in patients with acute MI (Data). Myocardial necrosis results in elevated cardiac enzyme levels (Warrant).” This result demonstrates many students’ lack of integrating basic mechanisms that may be responsible for the patient’s problem into their inquiry strategies that will produce useful information to validate the hypotheses entertained.

Data analysis/synthesis. In this phase, the students discussed the patient’s data obtained from the inquiry strategies. The total number of arguments generated during this phase was the second highest (*mean of frequency* = 74.5) after the number of arguments in the hypothesis generation (*mean of frequency* = 75). However, almost three-fourths of the arguments constructed during this phase were taken up by incomplete (Type 0) arguments (*mean of frequency* = 53, 71.1%). Most students simply repeated the factual information obtained from inquiry strategies (e.g., results of lab tests) without interpreting the patient’s data (e.g., “The patient said that he has hypertension and hyperlipidemia.”). The students seemed to have difficulty analyzing the data and determining how test results were related to a more likely hypothesis. The number of words in Type 0 arguments was the highest (*word count* = 277.5, 39.3%) among the four types of arguments made during this phase, and the students generated more Type 2 arguments (*frequency* = 9, 12.1%) than Type 1 arguments (*frequency* = 5.5, 7.4%). An example of a Type 2 argument is “Because ST segment elevation in the EKG appears (Data), there can be ischemia (Claim).” Arguments including claims with data and warrants (Type 3 arguments) accounted for 9.4% (*frequency* = 7) of the total (*frequency* = 74.5). An example of Type 3 arguments is "From blood test results, the LDH [lactate dehydrogenase] levels are high (Data). The LDH levels may be increased when there is cell necrosis (Warrant). I think myocardial cell necrosis is likely (Claim)." We only found one or two students per group who were strongly and recurrently predisposed to make a claim (an interpretation of the obtained patient's data), providing data or data and warrants. This indicates that these students might have learned how to interpret test results for the hypotheses generated in the first session through their self-directed study between the first and second sessions. The large number of incomplete arguments made during this phase may also be attributed to students' lack of knowledge and skills in interpreting test results (Ju et al., in press). Although the number of Type 3 arguments was the lowest (*frequency* = 7) among the total arguments made, Type 3 arguments had the second largest number of words (*word count*= 233, 33%) after Type 0 arguments (*word count* = 277.5, 39.3%).

Diagnostic decision. The primary activity in this phase involved deciding on the most likely clinical diagnosis of the patient's problem. The students generated the fewest arguments during this phase that accounted for 0.9% (*mean of frequency* = 2.5) of the total arguments (*mean of frequency* = 280.5) constructed during all of the HDR phases. This may be because this phase required students' convergent thinking to come to a conclusion about a particular diagnosis (Barrows, 1985; Barrows & Tamblyn, 1980). In fact, when one or two students in a group initiated arguments about a patient's diagnosis, other group members tended to agree with the ideas while spending a small amount of time on this phase (about 3 minutes per group). More importantly, all of the arguments produced in this phase were either Type 2 arguments (claims with data) or Type 3 arguments (claims with data and warrants). This indicates that the students advanced their arguments by advocating for their diagnostic decisions to a certain degree as they practiced their analyses of the patient's data obtained from their inquiry and as they studied and integrated related basic mechanisms toward the validation of the hypothesis entertained. Of the total arguments raised, Type 2 arguments accounted for 40% (*frequency* = 1). The data for the claims used by the students were the patient's significant data acquired from the data analysis/synthesis. For example, one student said, "I think acute MI is most likely (Claim), because we identified ST segment elevation in lead II, III, and aVF and a reciprocal ST segment depression in V1 to V4 from the EKG (Data). Also, we identified a problem with the inferior wall from the echocardiography and obstruction of the RCA from the cardiac angiography (Data)." A total of three arguments (1.5 per group) included data and warrants to justify their claims about the diagnosis of the patient (Type 3 arguments), using knowledge of pathophysiological mechanisms as warrants. An example of a Type 3 argument is "We identified an obstruction of the RCA [right coronary artery] (Data) that results in left ventricle inferior wall damage (Warrant). So, we can conclude that our diagnosis is acute MI (Claim)." Type 3 arguments were generated more often (*frequency* = 1.5, 60%) than Type 2 arguments (*frequency* = 1, 40%), but the number of words in Type 3 arguments (*word count* = 39.5, 46.5%) was lower than the number of words in Type 2 arguments (*word count* = 45.5, 53.5%).

Therapeutic decision. In this phase, the students came up with suggestions for treating the patient medically, surgically, or psychologically. The total number of arguments made during this phase accounted for about 26% (*mean of frequency* = 72) of the total arguments constructed during all of the HDR phases (*mean of frequency* = 280.5), and these numbers were almost as high as the numbers of arguments made during the hypothesis generation and data analysis/synthesis phases. This can be explained by the students being asked to generate multiple ideas and make decisions about treatment or management plans for the patient's problem through divergent and convergent thinking. Of the arguments raised during this phase, Type 1 and Type 2 arguments accounted for 32.6% (*frequency* = 23.5) and 41.7% (*frequency* = 30) respectively. The following are examples of Type 1 arguments: "We should prescribe nitroglycerin (Claim)" and "Coronary artery bypass graft surgery will be needed (Claim)." For Type 2 arguments, they used the patient's data or diagnosis as data (evidence) for their claims. An example of a Type 2 argument is "I think CABG (coronary artery bypass graft) surgery may be needed (Claim), because the patient has hyperlipidemia and hypertension (Data)." The number of words in Type 2 arguments was the highest among the four types of arguments made during this phase (*word count* = 591.5, 39.9%). There were incomplete (Type 0) arguments that accounted for about 10% (*frequency* = 7) of the total (*frequency* = 72). For example, when one student stated, "It should be necessary to provide oxygen," another student added, "Because the patient has very low oxygen saturation levels (Incomplete)." Also, arguments including claims, data, and warrants (Type 3 arguments) accounted for 16% (*frequency* = 11.5) of the total (*frequency* = 72). In Type 3 arguments, the students used knowledge about the effectiveness or side effects of the treatment considered necessary or basic mechanisms related to the treatment intervention as warrants for justifying their claims and data to a certain degree. For example, "I think that preventing complications of fibrinolysis or PCI [percutaneous coronary intervention] will be necessary (Claim) for a patient with MI (Data). Allergic reactions to the streptokinase used in fibrinolysis or hypotension after PCI may occur in the patient (Warrant)," We found that the students seemed to be deficient in using biomedical knowledge, which can be used to explain how treatment strategies considered important can improve the patient's condition in terms of pathophysiological mechanisms, as warrants to reveal the relevance of their claims and data.

This may suggest that the students need to be guided in integrating knowledge of basic pathophysiological mechanisms into the ways in which diseases can be treated so that they can understand the basic mechanisms of a patient's problem, which is one of important goals of PBL (Barrows, 1985, 1994; Barrows & Tamblyn, 1980). The word count in Type 3 arguments made up about 39% (*word count* = 575) of the total word count in this phase (1483.5).

Conclusion

Recommendations to Improve Students' Argumentation

The findings of this study demonstrate that the students predominantly made claims without proper justifications (data and warrants) which are important components in constructing sound arguments. This indicates the need for pedagogical interventions to improve the quality of arguments generated by students during PBL.

One strategy for supporting the students' argument construction can be to help the students understand the structure of a sound argument. Some researchers argued that students' naïve conceptions of argument structures can cause the production of weak arguments (Cerbin, 1988; Zeidler, 1997). Therefore, to assist students in understanding the nature of arguments and argument structures, students should be provided with opportunities to learn the basic components of a valid argument and practice constructing arguments during PBL orientations. For effective learning and practicing argumentation, visual argumentation tools could be used that can allow students to construct arguments in a graphical form on paper or through computer software. This can enable students to organize their thinking visually and identify the strengths and weaknesses of their arguments (Chin & Osborne, 2010; Toth, Suthers, & Lesgold, 2002).

The tutors' questioning could also be an effective intervention for enhancing the students' argumentation. In PBL, tutors are supposed to play a role in facilitating students' learning processes rather than directly providing knowledge or information for students (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Dolmans, Wolfhagen, van der Vleuten, 2003; Hmelo-Silver & Barrows, 2008; Schmidt, Rotgans, & Yew, 2011). During each HDR phase, a tutor could encourage the students to provide evidence for supporting their claims and to explain the basic mechanisms of a patient's problem through his/her questioning. Examples of tutor's questions to be asked during HDR processes are as follows: "What ideas do you have as to what basic mechanisms might be involved in this patient's problem?" during the hypothesis generation phase; "How is the result related to basic mechanisms?" in the data analysis phase; and "Can you explain how the treatment can correct the patient's problem?" in the therapeutic decision phase (Barrows, 1985). These tutors' questions will assist the students in building a causal model for a patient's problem while seeking relevant data and pathophysiological principles.

One of important goals in PBL is to help medical students understand the basic mechanisms of a patient's problem, applying basic scientific knowledge (e.g., physiology and biochemistry) to clinical contexts as they practice the HDR process (Barrows 1985, 1994; Barrows & Tamblyn, 1980) through argumentation. However, this study revealed that the students lacked the abilities to provide data for a claim and relevant warrants explaining the connection between their claims and data in their HDR processes performed during their small group discussion sessions. Our further analysis and discussion about the medical students' argumentation in relation to HDR processes contributed to understanding how students engage in HDR processes during PBL, how they produce arguments, and how their arguments can be enhanced.

Limitations and Future Research

For limitations of this study, firstly, our data analysis was based on statements verbally expressed by students. Given the PBL situation in which students exchange their ideas with one another, the students' actual thinking processes could be different from what they explicitly stated. Secondly, the quality of each component of an argument (a claim, data, and a warrant) students constructed was not evaluated. For example, although some students could provide warrants to justify their claims and data during HDR processes, the quality of their warrants might have been different. Lastly, the findings of this study are limited by a clinical case problem used for the PBL block course and first-year preclinical medical students, which presents a small sample size.

For future research, it may be necessary to analyze students' arguments through an advanced analytical framework for capturing the flow of group discussion. Additional research will be needed to assess the quality of the components of each type of argument with respect to HDR processes (e.g., as warrants, basic mechanisms are accurate and relevant to a patient's clinical case), which may be helpful for evaluating students' abilities to provide coherent explanations for a patient's problem and apply relevant basic scientific knowledge to clinical contexts. Moreover, further studies should include other clinical case problems using PBL with a larger sample size, and the pedagogical interventions we have discussed for promoting medical students' argumentation in PBL should be validated in future research.

References

Andrews, R. (2005). Models of argumentation in educational discourse. *Text - Interdisciplinary Journal for the Study of Discourse, 25*(1), 107–127. doi:10.1515/text.2005.25.1.107

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years.* New York, NY: Springer.

Barrows, H. S. (1994). *Practice-based learning: Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York, NY: Springer.

Bligh, D. (2000). *What's the point in discussion?* Portland, OR: Intellect Books.

Cerbin, B. (1988). *The nature and development of informal reasoning skills in college students.* Retrieved from ERIC database (ED298 805).

Chin, C., & Osborne, J. (2010). Supporting argumentation through students' questions: case studies in science classrooms. *Journal of the Learning Sciences*, *19*(2), 230–284.

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement, 20*(1), 37–46. doi:10.1177/001316446002000104

Croskerry, P. (2009). A universal model of diagnostic reasoning. *Academic Medicine, 84*(8), 1022–1028. doi:10.1097/ACM.0b013e3181ace703

Dickinson, H. D. (1998). Evidence-based decision-making: An argumentative approach. *International Journal of Medical Informatics*, *51*(2–3), 71–81. doi:10.1016/S1386-5056(98)00105-1

Dolmans, D. M., Wolfhagen, H. P., & van der Vleuten, C. M. (2003). Development of an instrument to evaluate the effectiveness of teachers in guiding small groups. *Higher Education, 46*(4), 431–446.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education*, *84*(3), 287–312. doi:10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Elstein, A. S. (1995). Clinical reasoning in medicine. In J. Higgs & M. A. Jones (Eds.), *Clinical reasoning in the health professions* (pp. 49–59). Boston, MA: Butterworth-Heinermann.

Frederiksen, C. H. (1999). Learning to reason through discourse in a problem-based learning group. *Discourse Processes, 27*(2), 135–160. doi:10.1080/01638539909545055

Groves, M. (2007). The diagnostic process in medical practice: The role of clinical reasoning. In E. M. Vargios (Ed.), *Educational psychology research focus* (pp. 133–184). New York, NY: Nova Science Publisher.

Groves, M. (2012). Understanding clinical reasoning: The next step in working out how it really works. *Medical Education, 46*(5), 444–446. doi:10.1111/j.1365-2923.2012.04244.x

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn?. *Educational Psychology Review, 16*(3), 235–266. doi:10.1023/B:EDPR.0000034022.16470.f3

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction*, *26*(1), 48–94. doi:10.180/07370000701798495

Jiménez-Aleixandre, M. P., & Rodriguez, A. B. (2000). “Doing the lesson” or “Doing science”: Argument in high school genetics. *Science Education*, *84*(6), 757–792.

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments.* New York, NY: Routledge.

Ju, H., Choi, I., Rhee, B., & Lee, J. (in press). Challenges experienced by Korean medical students and tutors during problem-based learning: A cultural perspective. *The Interdisciplinary Journal of Problem-Based Learning.*

Kim, J., Son, H., Choi, Y., Hong, K., Ahn, B., Uhm, D., Chin, Y., . . . Seo, J. (2004). A qualitative evaluation of problem-based learning curriculum by students' perceptions. *Korean Journal of Medical Education*, *16*(2), 179–193.

Kempainen, R. R., Migeon, M. B., & Wolf, F. M. (2003). Understanding our mistakes: A primer on errors in clinical reasoning. *Medical Teacher, 25*(2), 177–181. doi:10.1080/0142159031000092580

Kuhn, D. (1992). Thinking as argument. *Harvard Educational Review, 62*(2), 155–178.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1). 159–174. doi:10.2307/2529310

Lu, J., Chiu, M. M., & Law, N. W. (2011). Collaborative argumentation and justifications: A statistical discourse analysis of online discussions. *Computers in Human Behavior, 27*(2), 946–955. doi:10.1016/j.chb.2010.11.021

McNeill, K. L., & Krajcik, J. (2007). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In M. Lovett & P. Shah (Eds.), *Thinking with data* (pp. 233–265). New York: Taylor & Francis.

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences, 15*(2), 153–191. doi:10.1207/s15327809jls1502_1

Nussbaum, E. M. (2011). Argumentation, dialogue theory, and probability modeling: Alternative frameworks for argumentation research in education. *Educational Psychologist*, *46*(2), 84–106. doi:10.1080/00461520.2011.558816

Patel, V. L., Arocha, J. F., & Zhang, J. (2005). Thinking and reasoning in medicine. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 727–750). New York, NY: Cambridge University Press.

Patton, M. Q. (2015). *Qualitative research & evaluation methods* (4th ed.). Thousand Oaks, CA: Sage.

Sackett, D. L., Rosenberg, W. C., Gray, J. M., Haynes, R. B., & Richardson, W. S. (1996). Evidence based medicine: What it is and what it isn't. *BMJ: British Medical Journal*, *312*(7023). 71–72. doi:10.1136/bmj.312.7023.71

Savery, J.R., & Duffy, T. M. (2001). Problem-based learning: An instructional model and its constructivist framework. *Educational Technology*, *35*(5), 31–38.

Schmidt, H. G., Rotgans, J. I., & Yew, E. H. (2011). The process of problem-based learning: what works and why. *Medical Education*, *45*(8), 792–806. doi:10.1111/j.1365-2923.2011.04035.x

Sefton, A., Gordon, J., & Field, M. (2008). Teaching clinical reasoning to medical students. In J. Higgs & M. A. Jones (Eds.), *Clinical reasoning in the health professions* (3rd ed.) (pp. 469–476). Boston, MA: Butterworth-Heinermann.

Siegel, H. (1995). Why should educators care about argumentation? *Informal Logic*, *17*(2), 159–176.

Terry, W. W., & Higgs, J. J. (1993). Educational programmes to develop clinical reasoning skills. *Australian Journal of Physiotherapy*, *39*(1), 47–51. doi:10.1016/S0004-9514(14)60469-4

Toth, E. E., Suthers, D. D., & Lesgold, A. M. (2002). “Mapping to know”: The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education, 86*(2), 264–286. doi:10.1002/sce.10004

Toulmin, S. (1958). *The uses of argument.* Cambridge: Cambridge University Press.

Toulmin, S. (2003). *The uses of argument.* Cambridge: Cambridge University Press.

van Eemeren, F. H., Grootendorst, R., Henkemans, F. S., Blair, J. A., Johnson, R. H., Krabbe, E. C. W., … Zarefsky, D. (1996). *Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments.* Mahwah, NJ: Lawrence Erlbaum Associates.

Visschers-Pleijers, A. J., Dolmans, D. H., Leng, B. A., Wolfhagen, I. H., & van der Vleuten, C. P. (2006). Analysis of verbal interactions in tutorial groups: A process study. *Medical Education, 40*(2), 129–137. doi:10.1111/j.1365-2929.2005.02368.x

von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching, 45*(1), 101–131. doi:10.1002/tea.20213

Yeo, S., & Chang, B. H. (2016). Students’ perceptions and satisfaction level of hybrid problem-based learning for 16 years in Kyungpook National University School of Medicine, Korea. *Korean Journal of Medical Education, 28*(1), 9–16. doi:10.3946/kjme.2016.4

Zeidler, D. L. (1997). The central role of fallacious thinking in science education. *Science Education, 81*(4), 483–496. doi:10.1002/(SICI)1098-237X(199707)81:4<483::AID-SCE7>3.0.CO;2-8

CHAPTER 4

ENHANCING MEDICAL STUDENTS' ARGUMENTATION DURING HYPOTHETICO-DEDUCTIVE REASONING (HDR) IN PROBLEM-BASED LEARNING (PBL)[3]

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Abstract

This study sought to examine the effects of instruction on the structure of argumentation and question prompts (ISA-QP) on medical students' argumentation during hypothetico-deductive reasoning (HDR) processes in problem-based learning (PBL). This study was conducted at a Korean medical school from 2014 to 2015 and used a mixed methods research design. For the quantitative portion of the study, the frequencies of four different levels of argumentation were compared between control and experimental groups of first-year preclinical students during HDR processes in PBL. For the qualitative portion, semi-structured interviews with eight students from the experimental group and eight tutors were conducted and analyzed through the constant comparative method. For the overall HDR processes, the experimental group generated more high-level arguments than the control group, and the chi-square test revealed significant differences in the quality of argumentation between the two groups. The chi-square tests for each HDR phase showed the quality of argumentation between the two groups significantly differed in the hypothesis generation and inquiry strategy phases. The students in the experimental group had some positive experiences, such as focused statements and reflection, and the tutors had a clear understanding of argumentation and learned how to guide students' argumentation during the HDR process, but the students and tutors faced several challenges. These findings suggest that the instruction on the structure of argumentation and question prompts (ISA-QP) provided for students and tutors can enhance the quality of students' argumentation during the HDR process in PBL and the quality of experiences with PBL for students and tutors.

Keywords: instruction on the structure of argumentation, question prompts, argumentation, hypothetico-deductive reasoning (HDR), problem-based learning (PBL)

Introduction

Problem-based learning (PBL) is expected to help medical students develop their hypothetico-deductive reasoning (HDR) skills (Barrows, 1985, 1994, 1996; Barrows & Tamblyn, 1980). The HDR process involves generating hypotheses and validating those hypotheses, which can often be employed when there are insufficient experiences and knowledge related to a clinical problem encountered or when problem solutions are unambiguous (Higgs & Jones, 1995; Patel, Arocha, & Zhang, 2005). The HDR process can provide an appropriate framework of medical problem solving for medical students who find most clinical problems unfamiliar and have a lack of domain knowledge and clinical experiences (Elstein, 1995), which is incorporated in PBL (Barrows, 1994; Patel et al., 2005).

Students are encouraged to work together for solving medical problems through small group discussions in PBL (Barrows, 1985; Barrows & Tamblyn, 1980; Hmelo, 1998; Hmelo-Silver & Barrows, 2008; van Berkel & Dolmans, 2006). For problem solving, central to the process of thinking and reasoning is argumentation—a social process of generating, exchanging, and evaluating ideas with others and providing justifications for the ideas (Cerbin, 1988; Jiménez-Aleixandre & Rodriguez, 2000; Jonassen, 2011; Kuhn, 1992; van Eemeren et al., 1996). In PBL, it is necessary for medical students to engage in argumentation to provide related evidence for their claims and reasoning from the claims and evidence and to apply basic science knowledge in clinical contexts. This will assist the students in building causal explanations of a patient's problem and taking a coherent approach to scientific inquiry for problem solving about a patient's condition while dealing with a patient's clinical information or data, which both involve the HDR process (Frederiksen, 1999; Hmelo-Silver & Barrows, 2008). That is, facilitating students' argumentation during small group discussion in PBL would be helpful for enhancing their HDR abilities.

Students' reasoning and problem solving abilities are based on their proficiency in justifying their claims with evidence and warrants (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Newton, Driver, & Osborne, 1999; Siegel, 1995). However, several studies have reported that students have difficulty constructing reasoned arguments during scientific inquiry processes; for example, students did not provide relevant observational data to support their claims or make theoretical explanations to justify the connection between their claims and evidence (Jiménez-Aleixandre & Rodriguez, 2000; McNeill & Krajcik, 2007; McNeill, Lizotte, Krajcik, & Marx, 2006). In line with the students' challenges in argument construction, Patel and her colleagues (1989) found that medical students engaged in PBL did not construct a coherent explanation to connect their ideas about possible causes of a patient's problem to a patient's clinical presentations (e.g., symptoms and signs). Also, a study focusing on an analysis of medical students' argumentation during small group HDR processes in PBL reported that students predominantly made claims without justifications rather than producing claims with data or data and warrants (see Chapter 3). It was also found that most students in the study seemed to have difficulty providing explanations for a patient's problem in terms of basic mechanisms as warrants necessary for scientific argumentation in the HDR process. These findings suggest instructional strategies for facilitating medical students to construct sound arguments during PBL are needed, which can help improve their HDR abilities.

Strategies for Enhancing Students' Argumentation

Instruction on the structure of argumentation. One strategy for supporting medical students' argumentation during PBL could be to help students understand the structure of argumentation. Several researchers (e.g., Cerbin, 1988; Sanders & Wiseman, 1994) argued that instruction on the structure of argumentation can improve students' argumentation skills, since some students who do not have a clear understanding of an argument's structure are more likely to generate weak arguments. Toulmin's (1958, 2003) argumentation model has been used to teach students the structure of argumentation that specifies components of an argument to make their data or warrants for supporting their claims more explicit (Hewson & Ogunniyi, 2010; Newton et al., 1999; Nussbaum, 2011). Providing learners with an organizational scheme used for argumentation can encourage them to internalize a model of an argument's structure, construct more rigorous arguments, and evaluate their own arguments (Buckingham Shum, MacLean, Bellotti, & Hammond, 1997; Cerbin, 1988; Chin & Osborne, 2010; Jonassen, 2011). For example, using an argument diagram assisted students in understanding the structure of arguments (Chin & Osborne, 2010) and making the key elements of arguments obvious (Chin & Osborne, 2010; Toth, Suthers, & Lesgold, 2002), and students who were facilitated to represent their arguments diagrammatically generated more evidence for their claims and transferred the ability to make arguments to their later tasks, more so than those who were not (Suthers & Hundhausen, 2003). In addition to the effort to support students' understanding of an argument structure, it may be necessary for teachers themselves to understand the structure of argumentation so that they can promote students' argumentation in classrooms (McNeill & Knight, 2013; McNeill & Krajcik, 2008; Sampson & Blanchard, 2012; Simon, Erduran, & Osborne, 2006). Previous research exploring how to support students' scientific argumentation in K-12 settings suggested that teachers themselves, who do not know the purpose of argumentation and the structure of a scientific argument, can experience challenges when guiding their students in forming well-reasoned arguments or using appropriate instructional strategies, such as using examples and questioning, when students are struggling to provide justifications for supporting their claims (McNeill & Knight, 2013; McNeill et al., 2006; Simon et al., 2006). In PBL, tutors need to facilitate medical students to construct sound arguments during HDR processes. It would be essential for tutors to identify the structure of argumentation with respect to the HDR process so that they can provide students with appropriate assistance and guidance for argumentation, such as through monitoring, questioning, or giving effective feedback, which can empower the quality of arguments elicited by students.

Thus, in an attempt to improve the quality of medical students' argumentation during PBL sessions, both students and facilitators need an opportunity to gain a clear understanding of the structure of argumentation, such as through a workshop or argumentation lesson, and a study examining its effects on students' argumentation during HDR processes in PBL is required.

The use of questions. Another strategy for enhancing medical students' argumentation during PBL could be using questions. Questioning is considered as a cognitive component that stimulates students' thinking and reasoning (Graesser, Bagget, & Williams, 1996; Larson & Lovelace, 2013) and is used to promote students' argumentation in problem solving (Chin & Osborne, 2010; Erduran, Simon, & Osborne, 2004; Graesser et al., 1996; Jonassen, 2011; Larson & Keiper, 2002; Osborne, Erduran, & Simon, 2004). Teachers' questioning can serve as a scaffold to prompt students' argumentation. Previous studies (e.g., McNeill & Pimentel, 2010; Veerman, Andriessen, & Kanselaar, 2002) showed that teachers' questions, requiring students to generate their ideas explicitly and explain their reasoning, helped students construct cogent arguments, reflect on their claims, and provide more justifications. In addition, Hmelo-Silver and Barrows (2008) reported that facilitators' questions about causal antecedents and consequences helped medical students build casual explanations of a patient's problem, using knowledge of pathophysiological mechanisms during PBL sessions. Besides tutors' questioning, students' use of question prompts based on the structure of argumentation can guide their argumentation. According to Jonassen and his colleagues (Jonassen & Kim, 2009; Oh & Jonassen, 2007), students who used question prompts based on Toulmin's (1958) argumentation model not only improved their performance in solving ill-structured problems but also produced more justifications to support their claims than those who did not use them. Aided by prepared question prompts, posing questions to themselves about the structure of argumentation and the content of their thinking and reasoning would have the potential for taking the nature of argumentation into consideration, which can lead to generating more sophisticated arguments (Chin & Osborne, 2010; Erduran et al., 2004). Lawson (2003) proposed that "more advanced reasoning begins when individuals ask questions, not of others, but of themselves" (p. 1398), and this may enable students to develop the ability to initiate scientific argumentation and reasoning. Although there are some studies that investigated the effectiveness of teachers or students' use of questions in enhancing students' argumentation, there is little research focusing on the effects of this strategy on medical students' argumentation during HDR processes in PBL.

Purpose of the Study

The purpose of this study was to examine the effects of instruction on the structure of argumentation and question prompts (ISA-QP) on medical students' argumentation during HDR processes in PBL. With regard to the instruction on the structure of argumentation (ISA), both students and PBL tutors were given a workshop before participating in certain PBL courses. In terms of the use of question prompts (QP) for argumentation, both students and PBL tutors were provided with a set of question prompts developed based on the structure of argumentation applied to each phase of HDR. The following research questions guided this study:

1. How effective are the instruction on the structure of argumentation and question prompts (ISA-QP) during HDR processes in PBL?
   (a) What are the differences in the quality of argumentation during the overall HDR process in PBL between medical students who received the instruction on the structure of argumentation and question prompts (ISA-QP) and those who did not?
   (b) What are the differences in the quality of argumentation during each phase of HDR in PBL between medical students who received the instruction on the structure of argumentation and question prompts (ISA-QP) and those who did not?
2. What are students' experiences with argumentation during HDR processes in PBL?
   (a) What are students' experiences regarding argumentation after receiving the instruction on the structure of argumentation and question prompts (ISA-QP)?
   (b) What are students' perceptions of the instruction on the structure of argumentation and question prompts (ISA-QP) in relation to their argumentation activity?
3. What are tutors' experiences with facilitating students' argumentation during HDR processes in PBL?
   (a) What are tutors' experiences with facilitating students' argumentation after receiving the instruction on the structure of argumentation and question prompts (ISA-QP)?
   (b) What are tutors' perceptions of the instruction on the structure of argumentation and question prompts (ISA-QP) in relation to their facilitation of students' argumentation activities?

Methods

Research Design

This study used a mixed methods research design that involves collecting both quantitative and qualitative data (Creswell, 2014) for the purpose of complementarity (Greene, 2007) to seek broader and more comprehensive understandings of how the instruction on the structure of argumentation and question prompts (ISA-QP) influence students' argumentation, addressing three different research questions (see Table 4.1).

As an overall research design, a quasi-experimental design, a non-equivalent control group posttest only design (Cook & Campbell, 1979) was employed. The independent variable in this study was the presence or absence of instruction on the structure of argumentation and question prompts (ISA-QP) (explained in the "Intervention" section): (1) a control group that did not receive the ISA-QP and (2) an experimental group that received the ISA-QP. The quality of arguments constructed by students during HDR processes in PBL was compared between the control and experimental groups through quantitative analyses of students' argumentations. In this study, the quality of argumentation is defined in terms of the presence or absence of a claim and the occurrence of single ("claim"), double ("claim-data"), and triple ("claim-data-warrant") combinations of three essential components (a claim, data, and a warrant) based on Toulmin's (1958, 2003) argumentation model. In other words, while an argument without a claim, which includes only data or a warrant, is considered the lowest quality of argument, an argument with all three components, including a claim, data, and a warrant, is considered the highest quality of argument.

Concurrent with the quantitative data collection, qualitative data were collected through individual semi-structured interviews with students from the experimental group and tutors to gain a deeper understanding of the impact of the ISA-QP on students' argumentation during PBL sessions.

Table 4.1

Alignment of Research Questions, Data Collection and Analysis Methods

Research Question	Data Collection	Data Analysis
1. How effective are the instruction on the structure of argumentation and question prompts (ISA-QP) during HDR processes in PBL?	**Quantitative** Through students' argumentation analysis using a coding scheme	
(a) What are the differences in the quality of argumentation during the overall HDR process in PBL between medical students who received the ISA-QP and those who did not?	• The frequency of each level of arguments generated during the overall HDR process	• Chi-square test
(b) What are the differences in the quality of argumentation during each phase of HDR in PBL between medical students who received the ISA-QP and those who did not?	• The frequency of each level of arguments generated during each HDR process	• Chi-square test
2. What are students' experiences with argumentation during HDR processes in PBL? (a) What are students' experiences regarding argumentation after receiving the ISA-QP? (b) What are students' perceptions of the ISA-QP in relation to their argumentation activity?	**Qualitative** Semi-structured interviews with students from the experimental group	• Constant comparison method
3. What are tutors' experiences with facilitating students' argumentation during HDR processes in PBL? (a) What are tutors' experiences with facilitating students' argumentation after receiving the ISA-QP? (b) What are tutors' perceptions of the instruction on the ISA-QP in relation to their facilitation of students' argumentation activities?	**Qualitative** Semi-structured interviews with tutors	• Constant comparison method

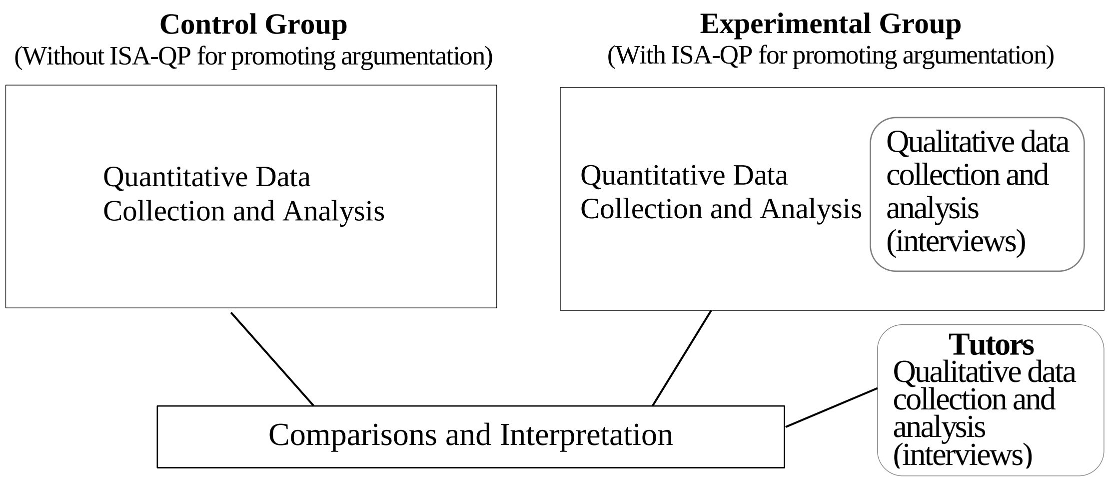


Figure 4.1. The research design for the study. ISA-QP = instruction on the structure of argumentation and question prompts.

Setting and Participants

Setting. This study was conducted in PBL courses for first-year preclinical students at a medical school in South Korea in the fall semester of 2014 and 2015. This school has implemented a PBL model proposed by Barrows (Barrows, 1985, 1994; Barrows & Tamblyn, 1980).

Two PBL courses for first-year preclinical students were used for this study in 2014 and 2015: (1) one PBL course was concerned with the cardiovascular system; the clinical case for the PBL courses in 2014 and 2015 was acute myocardial infarction (MI) with a standardized patient (SP) complaining of chest pain and dyspnea; and (2) the other PBL course concerned the respiratory system; the clinical case for the PBL course in 2014 was lung cancer with a SP complaining of hemoptysis, dyspnea, and a cough, and the clinical case for the PBL course in 2015 was endocardial tuberculosis (TB) with a SP complaining of coughing and wheezing. The interval of time between the cardiovascular PBL course and the respiratory PBL course was one month.

The first-year preclinical students were randomly assigned to one of 15 small groups, each having six to eight students; these groups remained unchanged for the cardiovascular and respiratory PBL courses. The faculty members were assigned to one of the 15 groups as tutors for a PBL course. Thus, each small group of six to eight students and one tutor participated in a one-week-long PBL course for each organ system (the cardiovascular and respiratory systems) in two-hour sessions three times a week (Monday, Wednesday, and Friday) and engaged in HDR processes during each of these three sessions.

The first session involved problem framing, hypothesis generation, inquiry strategy (e.g., history taking and physical examinations), and data analysis/synthesis using a standardized patient (SP); the second session included an inquiry strategy (e.g., laboratory tests), data analysis/ synthesis, diagnostic decisions, and therapeutic decisions (principles of managements); and the third session involved therapeutic decisions (short- and long-term managements). As each session got underway, students identified and made a list of their own group's learning goals (issues) that needed to be explored.

Participants. The participants for this study were a total of 58 first-year preclinical medical students—30 first-year students in 2014 and 28 first-year students in 2015 respectively—and eight tutors at the medical school.

The control group consisted of four small groups of seven to eight first-year preclinical students in 2014 (a total of 30 students), who were not provided with instruction on the structure of argumentation and question prompts (ISA-QP) during the two PBL courses (the cardiovascular and respiratory systems); and the experimental group consisted of four small groups of seven first-year preclinical students in 2015 (a total of 28 students), who were provided with instruction on the structure of argumentation and question prompts (ISA-QP) during the two

PBL courses (the cardiovascular and respiratory systems). For the control group, four out of a total of 15 PBL groups of first-year preclinical students in 2014 were selected through a criterion strategy (Patton, 2015) for the study. Initially, a total of eight tutors were selected through the criterion: tutors who have had experience tutoring PBL for more than two years and would most likely participate in PBL tutoring on either the cardiovascular or respiratory PBL courses through the following year (2015). Then, four of the eight selected tutors who would participate in the cardiovascular PBL course were each randomly assigned to one small group of seven to eight students out of the 15 small groups in 2014, and the other four of the eight selected tutors who would participate in the respiratory PBL course were each randomly assigned to one out of the four small groups in 2014.

For the experimental group, four PBL groups of first-year preclinical students in 2015 participated in this study among a total of 15 PBL groups who were provided with the instruction on the structure of argumentation and question prompts (ISA-QP). Across the two PBL courses, the four groups were facilitated by the same eight tutors who had facilitated the control group during the cardiovascular and respiratory PBL courses in 2014 respectively: four of the tutors had facilitated the control group during the cardiovascular PBL course in 2014 and were each randomly assigned to one small group of six to seven first-year preclinical students in 2015, and the other four tutors had facilitated the control group during the respiratory PBL course in 2014 and were each randomly assigned to one of the four small groups in 2015. The average GPA of the previous semester, before the semester including the two PBL courses for the control group and the experimental group, was a 3.17 and 3.10 respectively. In addition, for individual student interviews, two students from each of the four small groups in the experimental group (a total of 8 students) were randomly selected in order to explore students' experiences with the argumentation activity and perceptions of the instruction on the structure of argumentation and question prompts (ISA-QP).

Eight tutors who were selected through the criterion strategy mentioned above facilitated both the control group in 2014 and the experimental group in 2015 (four tutors for the cardiovascular PBL course and four for the respiratory PBL course). Also, all eight of the selected tutors participated in individual interviews. All of the student and tutor participants were informed about this study and voluntarily consented to be a part of this study.

Table 4.2

Participants

	Number of Participants		Number of Interviewees
Students	30	Control group (4 PBL groups of 1st year preclinical in 2014) * The average GPA: 3.17/4.50	
	28	Experimental group (4 PBL groups of 1st year preclinical in 2015) * The average GPA: 3.10/4.50	8
Total	58		
Tutors	4	Tutoring on the cardiovascular PBL course	4
	4	Tutoring on the respiratory PBL course	4
Total	8		

Intervention

Instruction on the structure of argumentation (ISA). Before starting the PBL course on the cardiovascular system in 2015, all of the 103 first-year preclinical students in 2015 and the 15 tutors who would facilitate the students' small groups in the cardiovascular PBL course were provided with a workshop about how to structure an argument during HDR processes; the workshop for the students and tutors lasted for 90 minutes and 60 minutes respectively. During the workshop, the students and tutors were given an explanation about the three essential components of an argument (a claim, data, and a warrant) and three additional components (backing, rebuttal, and qualifier) based on Toulmin's (1958, 2003) argumentation model using an argument diagram that represented the linkages between the components with specific examples (see Appendices A.2 & 3). Also, they were provided with opportunities to identify the structure of argumentation, including the three essential components (a claim, data, and a warrant), with respect to each HDR phase through an argument diagram and examples and participated in an activity about evaluating given arguments. Furthermore, in order for the students to practice constructing arguments, they were asked to make their arguments about questions (e.g., what is your hypothesis about this patient's case?). The workshop plan, based on Gagné's Nine Events of Instruction (Gagné, Wager, Golas, & Keller, 2005) is included in Appendix A.1.

Before the PBL course on the respiratory system in 2015, the same workshop was held for 15 tutors who would facilitate the students' small groups during the respiratory PBL course.

Question prompts for argumentation (QP). All of the 103 first-year preclinical students in 2015 and the 30 tutors (15 tutors for the cardiovascular PBL course and 15 for the respiratory PBL course) were offered question prompts (see Appendices B.1 & 2) for facilitating students' argumentation during HDR processes in PBL before starting each of the two PBL courses. The question prompts were developed based on the argumentation structure in relation to each HDR process (see Figure 4.2). The prompts included examples of general questions to guide students in the construction of arguments, including the three components (a claim, data, and a warrant), as well as examples of specific questions for argumentation in relation to each HDR phase for each session of PBL. At the end of the workshop on the structure of argumentation, the students and tutors were guided in using the question prompts for the two PBL courses on the cardiovascular and respiratory systems.

The Structure of Argumentation

HDR Phase	Data	Warrant	Claim
Problem Framing	Identified information or cues	Explanation why the identified information or cues are important	Initial concept of the patient's problem from the identified information or cues considered important
Hypothesis Generation	Identified information or cues recognized as important data	Pathophysiological mechanisms involved in the patient's problem	Basic mechanisms (anatomy, biochemistry, physiology, etc.) or disease entities that could be responsible for the patient's problem
Inquiry Strategy	Patient's information or cues organized by generated hypotheses	Basic mechanisms underlying the hypotheses entertained; information that the inquiry actions will produce	Actions or decisions on what information would be necessary
Data Analysis/ Synthesis	Data acquired from inquiry strategies	Basic mechanisms at the appropriate level	Interpretation on significant patient data that relate to the hypotheses considered
Diagnostic Decision	Rearranged significant patient data and its interpretations	Underlying responsible mechanisms involved in the patient's problem; diagnostic criteria for the most likely disease	Decision on the most likely hypothesis(es) responsible for the patient's problem
Therapeutic Decision	Diagnostic decision(s) with relevant patient's data	Basic mechanisms relating to the therapeutic interventions; research into the therapeutic efficacy of the chosen treatments	Decision on the approach to the treatment of the patient's problem

Figure 4.2. The structure of argumentation in the hypothetico-deductive reasoning process. Adapted from Chapter 3.

Quantitative Data Collection and Analysis

Through coding the students' argumentation, the frequency of each level of argument constructed by each participating group during HDR processes in PBL was collected.

Coding. Students' group discussions of all three PBL tutorial sessions for each of the two PBL courses (the cardiovascular and respiratory systems) for both the control and experimental groups were audio-recorded. The audio-recorded discussions of each condition group were transcribed verbatim. The unit of analysis was one argument verbally addressed by one student in each small group, including at least one of three essential components of an argument (a claim, data, and a warrant).

Coding scheme. The coding processes used for this study were adopted from the coding method of Chapter 3. First, segments of students' arguments dealing with the same topic within a series of interactions were identified and categorized into corresponding HDR phases using Barrows' (1994) HDR process: problem framing, hypothesis generation, inquiry strategy, data analysis/synthesis, diagnostic decision, and therapeutic decision. Next, each of the students' arguments was analyzed according to the three basic elements of an argument (a claim, data, and a warrant), using the argumentation structure in relation to each HDR phase (see Figure 4.2). For the analysis of each argument, only the component(s) explicitly indicated in each argument was coded. Given the PBL situation in which group members collaborate to solve problems through interactive discourse (Barrows & Tamblyn, 1980; Hmelo-Silver, 2004) and an assumption that some components of an argument can be left implicit (Nussbaum, 2011; Toulmin, 1958, 2003), it might be meaningful to identify implicit component(s) in students' arguments for understanding the flow and the quality of group discussion. However, defining and coding any implicit component(s) in an argument may be greatly affected by coders' interpretations based on his/her (medical) knowledge and experiences, which is a risk to the reliability of the analysis of the students' arguments. Thus, in this study, the explicit component(s) in arguments was coded to ensure the reliability, and then, each of the coded arguments was classified into one of four levels of arguments using a coding scheme to assess the quality of students' argumentation (see Table 4.3). A Level 0 argument is regarded as the lowest quality of argument, while a Level 3 argument is the highest quality of argument among the four levels of arguments.

Table 4.3

Coding Scheme for the Quality of Argumentation

Level of Argument	Description	Example
0	Data or warrant(s) without claim	The LDH [lactate dehydrogenase] levels are high (Data).
1	Claim without data and warrant(s)	I think acute MI [myocardial infarction] is likely (Claim).
2	Claim with data but no warrant(s)	The patient has chest pain (Data), so he may have angina (Claim).
3	Claim with data and warrant(s)	The patient complains of chest pain (Data). Pericardium inflammation is likely (Claim), because inflammatory substances can stimulate the surrounding nerves, which can cause chest pain (Warrant).

Note. Adapted from Chapter 3.

Inter-rater reliability. The first author reviewed the entire transcripts of discussions for the control and experimental groups over the two PBL courses and identified a total of 291 segments of students' arguments and 5,164 arguments—145 segments and 2,840 arguments for the control group and 151 segments and 2,324 arguments for the experimental group respectively.

A total of 24 segments (8% of the total segments), including 191 arguments (4% of the total arguments), were randomly selected and independently coded by the first (an education expert) and third (a medical educator) authors in order to estimate the inter-rater reliability.

Cohen's (1960) kappa was calculated for the coding of the levels of argument (k = .84) and for the coding of the segment type (HDR phases) (k =1).

Once acceptable levels of inter-rater reliability between the two reviewers were confirmed (Landis & Koch, 1977), the first author coded all of the remaining data (4,973 arguments in 267 segments). To obtain inter-rater reliability of the first author's coding, 225 arguments (5% of the total remaining arguments) in 7 segments (3% of the total remaining segments) were randomly selected and coded by the third author independently. Cohen's (1960) kappa was calculated; k = .85 for the coding of the levels of argument, and k = 1 for the coding of the segment type (HDR phases) respectively.

Analysis. To investigate the quality of argumentation for each condition (control and experimental) group according to the overall HDR process and each phase of HDR in each PBL course, descriptive statistics for the frequency of each level of argument were used. Also, we conducted chi-square tests for the overall HDR process and each phase of HDR respectively in order to ascertain the significance of the differences between the control and experimental groups in the mean frequency of different levels of arguments generated during the overall HDR process and each phase of HDR over two PBL courses.

The Qualitative Data Collection and Analysis Procedure

Semi-structured interviews with students. Semi-structured interviews with the selected students from the experimental group were conducted after the two PBL courses were completed. Each individual interview lasted for 25 to 30 minutes. The participants were asked questions about their experiences with argumentation during the HDR process and their perceptions of the instruction on the structure of argumentation and question prompts (ISA-QP) that they received (see Appendix C.1).

Semi-structured interviews with tutors. Semi-structured interviews with the selected tutors were conducted after each of the two PBL courses was completed. Each individual interview lasted for 20 to 25 minutes. During the interviews, the participants were asked questions about their experiences facilitating students' argumentation during the HDR process and their perceptions of the instruction on the structure of argumentation and question prompts (ISA-QP) for promoting students' argumentation (see Appendix C.2).

Analysis. All of the interviews were audio-recorded and transcribed verbatim. Throughout the process of analyzing the interview data, a basic word processing software, Microsoft Office Word, was used (Ruona, 2005). The constant comparative method was employed to identify meaningful themes by coding and organizing the interview data into categories (Charmaz, 2014; Glaser & Strauss, 1967; Merriam, 2009; Ruona, 2005). Each interview transcript was read first, and initial codes were formed by segmenting, highlighting, and labeling the text and comparing data with other data within each interview (Boeije, 2002; Charmaz, 2014). Then, focused codes were applied to several lines or paragraphs in the interview transcripts, using significant initial codes focusing more on interviewees' experiences or perceptions related to the argumentation activity or the instruction on the structure of argumentation and question prompts (ISA-QP) used for this study. During the focused coding, the constant comparative method was employed to identify patterns, revise terms, and combine, add, or eliminate codes (Charmaz, 2014; Glaser & Strauss, 1967). The focused codes that emerged from each interview were listed in tables in Word, and the relevant codes were identified, organized, and sorted into specific categories or themes according to principles of convergence (Boeije, 2002; Creswell, 2007; Ruona, 2005). A list of categories or themes was compiled into tables in Word and refined (Ruona, 2005). Constant comparisons were made between codes as well as between categories within and between interview data throughout the data analysis (Boeije, 2002; Charmaz, 2014; Glaser & Strauss, 1967).

Results

Frequency of Different Levels of Argumentation during the Overall HDR Process

After coding all of the students' arguments generated by each condition group during the two PBL courses (the cardiovascular and respiratory systems), the mean frequency of each level of argument was counted from each condition group. Table 4.4 shows descriptive statistics for the frequency of different levels of argumentation during the overall HDR process across the two PBL courses.

For the cardiovascular PBL course, the total numbers of arguments generated by the control group and the experimental group were 334.75 and 336.75 respectively; a difference between the two groups was 2. However, for the respiratory PBL course, a difference in the total numbers of arguments between the control and experimental groups was 131 (M_{control} = 375.25 and $M_{\text{experimental}}$ = 244.25), larger than the difference for the cardiovascular PBL course. The large difference in the total numbers of arguments constructed may be attributed to differences in the structuredness and complexity of the problem (Jonassen, 2011) used for the control group and experimental group; the patient's case used for the control group was concerned about lung cancer, but the patient's case used for the experimental group was tuberculosis (TB). TB seemed to be a more familiar disease to students than lung cancer, and most of the patient's information or clinical presentations (e.g., symptoms and signs) used for the experimental group indicated typical symptoms of TB, which might have led the experimental group to approach their problem-solving process more easily, producing fewer arguments during the overall HDR process than the control group dealing with a more complex problem, lung cancer. This may be interpreted as indicating that students who solve more ill-structured and complex problems can generate more arguments (Cho & Jonassen, 2002). However, for the quality of argumentation, the experimental group had higher proportions of Level 2 (claim with data) and Level 3 arguments (claim with data and warrant) than the control group, which shows that the instruction on the structure of argumentation and question prompts (ISA-QP) used for supporting students' argumentation affected the quality of the arguments.

Table 4.4

Descriptive Statistics for the Different Levels of Argumentation during the Overall Hypothetico-Deductive Reasoning Process

	Control group (n = 4)			Experimental group (n = 4)			Total		
Levels of Argument	*M*	*SD*	%[a]	*M*	*SD*	%[a]	*M*	*SD*	%[a]
Cardiovascular PBL									
Level 0: Incomplete	86.50	25.85	25.84	87.75	35.20	26.06	87.13	28.60	25.95
Level 1: Claim only	157.25	28.84	46.98	115.00	17.15	34.15	136.13	31.50	40.54
Level 2: Claim-Data	69.25	13.62	20.69	71.00	22.05	21.08	70.13	16.99	20.89
Level 3: Claim-Data-Warrant	21.75	6.24	6.50	63.00	19.34	18.71	42.38	25.75	12.61
Total[a]	334.75	68.37	100.00	336.75	76.08	100.00	335.75	66.97	100.00
Respiratory PBL									
Level 0: Incomplete	110.75	34.10	29.51	58.25	18.48	23.85	84.50	37.85	27.28
Level 1: Claim only	151.25	48.18	40.31	56.00	16.69	22.93	103.63	60.88	33.45
Level 2: Claim-Data	87.25	33.08	23.25	78.75	19.14	32.24	83.00	25.43	26.80
Level 3: Claim-Data-Warrant	26.00	8.04	6.93	51.25	13.23	20.98	38.63	16.88	12.47
Total[a]	375.25	84.58	100.00	244.25	46.71	100.00	309.75	94.36	100.00
Total									
Level 0: Incomplete	98.63	30.87	27.78	73.00	30.43	25.13	85.81	32.43	26.59
Level 1: Claim only	154.25	36.90	43.45	85.50	35.21	29.43	119.88	49.74	37.14
Level 2: Claim-Data	78.25	25.32	22.04	74.88	19.56	25.77	76.56	21.92	23.72
Level 3: Claim-Data-Warrant	23.88	7.04	6.73	57.13	16.57	19.66	40.50	21.12	12.55
Total[a]	355.00	74.42	100.00	290.50	76.55	100.00	322.75	80.18	100.00

Note. *M* = Mean of Frequency of Arguments; *SD* = Standard Deviation; *n* = Number of Small Groups; %[a] = % of the Total.

For the mean frequency of each level of arguments across the two PBL courses, we found that Level 1 arguments (claim only) was the most frequent level of arguments produced by the control group and the experimental group among the four levels of arguments. The experimental group had higher percentages of Level 2 (claim with data) and Level 3 arguments (claim with data and warrant) and lower percentages of Level 0 (incomplete) and Level 1 arguments (claim only) than the control group across the two PBL courses. A chi-square test was performed to examine the significance of differences in the frequencies of levels of argumentation between the two condition groups. The result revealed that the instruction on the structure of argumentation and question prompts (ISA-QP) had an impact on the quality of argumentation during the overall HDR process ($\chi^2 = 31.13$; $df = 3$; $p < .001$).

Frequency of Different Levels of Argumentation during Each HDR Phase

In order to examine differences in the quality of argumentation between the control and experimental groups during each phase of HDR, descriptive statistics of the frequency of each level of argumentation for the control and experimental groups in relation to each HDR phase across the two PBL courses were used (see Table 4.5). In each phase of HDR, the proportion of Level 3 arguments (claim with data and warrant) was higher in the experimental group than in the control group. To investigate whether significant differences in the quality of argumentation existed between the two groups during each phase of HDR, chi-square tests were performed, but Fisher’s exact tests were conducted for the Problem Framing and Diagnostic Decision phases instead of chi-square tests, because the expected frequency was less than 1 or more than 20% of the expected frequencies was less than 5 in the two phases (Fisher, 1970; Freeman & Julious, 2007).

Table 4.5

The Frequency of Arguments during Each Phase of Hypothetico-Deductive Reasoning

Levels of Argument		Hypothetico-Deductive Reasoning Phase												Total	
		Problem Framing		Hypothesis Generation**		Inquiry Strategy**		Data Analysis/ Synthesis		Diagnostic Decision		Therapeutic Decision			
		Control[a]	Experimental[a]	Control[a]	Experimental[a]	Control[a]	Experimental[a]	Control[a]	Experimental[a]	Control[a]	Experimental[a]	Control[a]	Experimental[a]	Control[a]	Experimental[a]
Level 0: Incomplete	*M*	4.25	4.50	13.13	14.88	6.88	11.50	57.13	31.50	4.63	3.00	12.63	7.63	98.63	73.00
	SD	3.24	2.39	10.27	6.77	5.14	7.89	21.96	12.68	4.24	2.93	7.11	6.00	30.87	30.43
	%[b]	55.74	50.00	13.17	16.60	9.32	14.00	62.69	59.72	39.36	34.78	17.75	15.76	27.78	25.13
Level 1: Claim Only	*M*	2.00	2.38	54.38	31.13	42.63	27.50	19.50	8.25	3.63	1.63	32.13	14.63	154.25	85.50
	SD	1.31	2.26	15.59	17.52	5.80	11.10	12.36	7.17	4.17	1.19	16.96	9.20	36.90	35.21
	%[b]	26.23	26.39	54.58	34.73	57.80	33.49	21.40	15.64	30.85	18.84	45.17	30.23	43.45	29.43
Level 2: Claim-Data	*M*	0.88	1.00	24.63	23.50	21.00	25.50	10.25	9.00	2.63	2.25	18.88	13.63	78.25	74.88
	SD	1.13	0.93	14.40	8.12	11.63	6.09	5.63	5.81	1.41	1.83	10.11	7.03	25.32	19.56
	%[b]	11.48	11.11	24.72	26.22	28.47	31.05	11.25	17.06	22.34	26.09	26.54	28.17	22.04	25.77
Level 3: Claim-Data-Warrant	*M*	0.50	1.13	7.50	20.13	3.25	17.63	4.25	4.00	0.88	1.75	7.50	12.50	23.88	57.13
	SD	0.76	0.83	3.82	8.43	2.25	6.30	3.54	3.78	1.13	1.04	4.54	5.35	7.04	16.57
	%[b]	6.56	12.50	7.53	22.45	4.41	21.46	4.66	7.58	7.45	20.29	10.54	25.84	6.73	19.66
Total	*M*	7.63	9.00	99.63	89.63	73.75	82.13	91.13	52.75	11.75	8.63	71.13	48.38	355.00	290.50
	SD	4.03	3.63	22.25	22.88	20.02	22.66	37.18	24.61	8.53	4.81	32.91	22.90	74.42	76.55
	%[c]	2.15	3.10	28.06	30.85	20.77	28.27	25.67	18.16	3.31	2.97	20.04	16.65	100.00	100.00

Note. *M* = Mean of Frequency of Arguments; *SD* = Standard Deviation; [a]*n* (Number of Small Groups) = 4; %[b] = % within the HDR Phase; %[c] = % of the Total.

** $p < .01$.

Problem framing. Students in the control and experimental groups generated much fewer arguments in this phase than in other phases of HDR (except the Diagnostic Decision phase). These low total frequencies of arguments may be because the students in the two groups had to formulate the patient's chief problem with very limited information obtained from the initial interview with the SPs during this phase. For each of the two groups, Level 0 (incomplete) arguments was the largest frequency level of arguments, which indicates that the students mentioned factual information that they heard or observed during the interview with the SPs before determining the patient's chief complaints. The experimental group generated lower percentages of Level 2 (claim with data) arguments, but higher percentages of Level 3 arguments (claim with data and warrant) than the control group. However, the Fisher's exact test showed no significant differences in the quality of argumentation between the control and experimental groups ($p = 1$), which indicates that the instruction on the structure of argumentation and question prompts (ISA-QP) did not have a significant effect on students' argumentation for this phase.

Hypothesis generation. The total numbers of arguments constructed by students in each of the two condition groups was the largest among all of the HDR phases. This reflects that the students generated many ideas responsible for the patient's problem through brainstorming and divergent, creative thinking (Barrows, 1985, 1994; Barrows & Tamblyn, 1980). The experimental group had lower percentages of Level 1 arguments, but higher percentages of Level 2 and Level 3 arguments than the control group did. The chi-square test showed that the frequency of different levels of argumentation significantly differed between the control group and the experimental group ($\chi^2 = 11.74$; $df = 3$; $p = .008$). This indicates that the students who received the intervention related to argumentation made more efforts to provide justifications for supporting their claims according to the structure of argumentation for this phase and incorporated more knowledge of pathophysiological mechanisms as warrants than the students in the control group.

Inquiry strategy. During this phase, students in the control and experimental groups came up with many suggestions for different inquiry actions, such as interview questions, physical examination items, and laboratory or diagnostic tests, in order to validate the multiple hypotheses they had generated, which resulted in the large total numbers of arguments generated. The students in the experimental group produced lower percentages of Level 1 arguments, but higher percentages of Level 2 and Level 3 arguments than those in the control group. This result indicates that the experimental group provided more specific reasons about why particular inquiry strategies would be important for the patient than the control group. As a result of the chi-square test, there were significant differences in the quality of argumentation between the two condition groups ($\chi^2 = 14.36$; $df = 3$; $p = .002$).

Data analysis/synthesis. The control and experimental groups generated incomplete (Level 0) arguments the most among the four levels of arguments during this phase. This shows that the students from both groups seemed to have challenges with interpreting the patient's data, such as the results of the X-rays or EKG tests, and explaining how the results define their hypotheses entertained, which may be explained by their lack of knowledge or skills in analyzing test results (Ju, Choi, Rhee, & Lee, in press). The experimental group had lower percentages of Level 1 arguments, but higher percentages of Level 2 and Level 3 arguments than the control group, which indicates the experimental group tried to construct sound arguments more than the control group, applying the argument structure for this phase. However, the chi-square test revealed no significant differences in levels of argumentation between the two groups ($\chi^2 = 1.96$; $df = 3$; $p = .580$).

Diagnostic decision. For the control group, this phase included the second smallest total frequencies of arguments, and the total frequencies of arguments generated by the experimental group during this phase was the smallest among all phases of HDR. This may be because that unlike the hypothesis generation phase that is a creative part of the HDR process, this phase is a narrow and logical process; the students made decisions about a certain clinical diagnosis for the patient's problem using the significant patient data obtained from data analysis and synthesis through convergent thinking (Barrows, 1985; Barrows & Tamblyn, 1980). The experimental groups produced lower percentages of Level 1 arguments, but higher percentages of Level 2 and Level 3 arguments. However, the Fisher's exact test suggested that the frequency of different levels of argumentation between the two groups did not significantly differ ($p = .869$), reflecting that the argumentation intervention (ISA-QP) had no significant effect on the quality of students' argumentation for this phase.

Therapeutic decision. The frequency of Level 1 arguments was the largest among the four levels of arguments in the control group and the experimental group respectively. This could be explained as the students from both groups tended to generate multiple ideas about necessary treatment strategies, such as surgery, medication, or patient's education, without explicitly providing justifications. However, the students from the experimental group produced lower percentages of Level 0 and Level 1 arguments, but higher percentages of Level 2 and Level 3 arguments than the control group. We found that the experimental group employed more knowledge of basic mechanisms as warrants in an effort to justify why particular treatment approaches should be provided for the patient than the control group did. However, the chi-square test showed no significant differences in the quality of argumentation between the control group and experimental group ($\chi^2 = 5.76$; $df = 3$; $p = .124$).

Students' Experiences

In order to address the research question, "What are students' experiences with argumentation during HDR processes in PBL?" semi-structured interviews with eight students from the experimental group were conducted. Through analyses of the interviews, eleven themes were identified: the students' positive experiences with the argumentation activity (6 themes), their challenges with the argumentation activity (2), and their experiences with the ISA-QP (3). Excerpts from the interview transcripts that were representative of the themes are presented. To protect participants' identities, we used numbers for participants' names (e.g., Student 1).

Focused statements/discussions. Several students found their discussions more focused than before applying the argument structures (*n* = 3). Student 4 responded in her interview, "We did not seem to say unnecessary words, though saying a single word." Another student [Student 1] said, "I learned what to do and why I was doing it in each [clinical reasoning] process, so my intent to say something in each process seemed to be conveyed well to the others. . . ." This shows that he had a clear understanding about the purposes of each reasoning phase in PBL through the structure of argumentation for the HDR processes, which led him and other groups members to pay more attention to what was being discussed during each process of HDR.

Reflection. Students' argumentation according to the argument structures allowed the students to reflect on what to say (*n* = 4); Student 6 said in his interview, "As a speaker, I had to rethink what to say to apply the [argument] structure before saying it. . . ." The students reported that they used to just say something without thinking before learning the argument structures, but they had become more deliberate in creating arguments. This shows that the required contents of each component of an argument (a claim, data, and a warrant) differ according to HDR phases, which stimulated the students to think about what should be included in their own arguments, framing the argument structures.

Refined ideas. Several students reported that they were able to refine what they would say in accordance with the argumentation structures in relation to the HDR process (*n* = 3). Student 3 addressed, "Generated ideas seemed to be filtered and refined to a certain degree." This may be related to students' reflection on what to say (mentioned earlier), which can help them logically organize their thoughts or ideas to be addressed and further clarify their arguments.

Systems thinking. The argumentation activity provided students with an opportunity to think more systemically than before (*n* = 3). For example, Student 4 said, "Following the argument structures helped me think about something systemically rather than just memorizing it; for example, one is linked to the others." This shows that applying the argument structures to their statements can support their understandings of relationships between concepts (i.e., structural knowledge, *know why*) rather than acquisition of declarative knowledge, *knowing that* (Duschl & Osborne, 2002; Huang, Chen, & Chen, 2009; Schwarz, Neuman, & Gil, 2003).

Identifying one's lack of knowledge. Students reported that they had more clear ideas about what they do not know during argumentation in PBL (*n* = 4). This is reflected in a students' response [Student 1], "I needed to say all of the components [a claim, data, and a warrant], but when I did not say a certain component of the three, I came to realize that I was unable to say it, because 'I do not know it now'." Additionally, these students' experiences had an impact on listing their learning goals (issues). Student 6 addressed, "We used to set abstract, broad learning goals, but this time, we have set specific, narrow learning goals about what we did not know."

This may be interpreted as indicating that the argumentation activity in accordance with the argument structures for the HDR process can encourage students to be self-aware of specific areas where more or better knowledge is needed (Barrows, 1985; Barrows & Tamblyn, 1980).

Guide for self-directed study. The argumentation activity appeared to guide the students' self-directed study (*n* = 4). Student 2 said, "For example, I had searched for only what necessary treatments were in the textbook before, but I began to study about not only what the necessary treatments are but also why the treatments are necessary." This indicates that the students seemed to pay more attention to justifications for supporting claims according to argument structures for the HDR process during PBL sessions as well as during their self-directed study.

Differences in individual students' participation. Generating arguments including at least the three components, a claim, data, and a warrant, made a difference in the extent to which students in a group participated in group discussions (*n* = 4). Student 6 commented, "Providing warrants requires a lot of knowledge, doesn't it? Within my group, there was a difference in expressing ideas between students who knew a lot and those who did not." This shows that students who lacked knowledge or were not prepared for PBL tutorial sessions were unwilling to produce and share their arguments, which can be related to students' tendencies toward hesitating to speak without correct and accurate knowledge (Ju et al., in press).

Unnatural discussions. Most students felt uncomfortable adhering to the argument structures during discussions (*n* = 7). Student 8 addressed, "My group members were more anxious about saying ideas according to the [argument] structure. . . . They became passive, and the discussion was less active than before." The students had had a habit of saying ideas without proper justifications for a long time, but they had to get into a new habit of constructing arguments, including the three components (a claim, data, and a warrant), which they might find challenging.

Utilization of the workshop material. Half of the students interviewed did not refer to the material (the handout) used for the workshop, and half used it only during the cardiovascular PBL course. One of those who used the material [Student 6] mentioned, “I used it [the handout] during the cardiovascular PBL course. It included examples of arguments. . . . For example, I have referred to it to remind me of how I should include warrants in my arguments.” Since the workshop was held just before the cardiovascular PBL course began, the students seemed to carry and use the workshop material during the cardiovascular PBL course, but did not seem to use the workshop material during the respiratory PBL course. Those who did not use the material during the two PBL courses reported that they referred to question prompts for their argumentation rather than the workshop material.

Utilization of the question prompts. All of the students interviewed used question prompts during the two PBL courses. The students found the question prompts useful for guiding their argumentation during PBL. The students addressed that they referred to the question prompts during discussions, because the prompts included self-guided questions about what to say as to each of the three primary components of an argument (a claim, data, and a warrant) for each phase of HDR. Student 3 responded in his interview, “They [the question prompts] let me know what I should say according to the [HDR] phases.”

Perceptions of tutors’ questioning. All of the students reported that tutors’ questions about their argumentation helped them construct sound arguments. For example, Student 4 said, “When my tutor asked a question about what warrant is in my arguments, I became aware of missing components of my arguments and added them to my arguments.” Also, tutors’ questions related to argumentation obviously encouraged students to identify what they needed to know. Student 2 responded in his interview, “When I provided data, my tutor asked me to think about warrants, which led me to realize that I did not know this and to think that I should study this.” This indicates that tutors’ questions could serve as specific feedback on students’ arguments as well as stimuli for students themselves to identify their learning goals (issues). However, four of the students found the tutors’ questions uncomfortable; Student 3 said, “After my tutor pointed out what we missed in our arguments or did not know, we did not want to say something in front of him, even if we had something to add.” This may be related to students’ challenges with speaking in front of teachers due to their avoidance of uncertainty, which was found in the previous study (Ju et al., in press).

Tutors’ Experiences

Semi-structured interviews with eight tutors were conducted in order to address the research question, “What are tutors’ experiences with facilitating students’ argumentation during HDR processes in PBL?” Through the tutor interview data analysis process, six themes were identified. Excerpts from the interview transcripts are presented with numbers substituted for participants’ names (e.g., Tutor 1) to conceal their identities.

Improved student argumentation. All of the tutors reported that students who were provided with the instruction on the structure of argumentation and question prompts (ISA-QP) tended to present data or warrants for supporting their claims during PBL sessions, compared to those who were not provided with any argumentation strategies (ISA-QP). Tutor 8 said, “When students made their claims, they tried to provide data and warrants [for the claims]. I found the quality of their discussions better [than the quality of the control group’s discussions].”

Additionally, the students in the experimental group seemed to make more efforts to explain pathophysiological mechanisms as warrants than the students in the control group.

Students' difficulty applying argument structures during the HDR process. Several tutors found that students who received the instruction on the structure of argumentation and question prompts (ISA-QP) seemed to experience challenges in constructing arguments using the structures of argumentation in relation to each phase of HDR (*n* = 3). According to tutors' responses, some students had had a tendency to generate their claims without data and warrants; Tutor 1 said, "Students had an old habit of not doing so [providing justifications], so doing so was hard for them." In addition, the students had a lack of knowledge for generating warrants. For example, Tutor 2 pointed out, "They [the students] wanted to provide warrants, but they did not have enough knowledge to do so." These students' challenges indicate that students were not accustomed to producing arguments that included a claim, data, and a warrant, and scientific argumentation in the HDR process requires students to use their prior knowledge, such as basic science and clinical knowledge.

Students' unnatural discussions. Several tutors found that students' discussions seemed awkward as the students in the experimental group engaged in the argumentation activity (*n* = 4); Tutor 4 said in her interview, "Students seemed to have had an obsession about saying data and warrants, since they learned that they needed to do so during the workshop. . . . They appeared to constrainedly classify their words into claims, data or warrants." This is related to the students' challenges with applying argument structures mentioned earlier.

Tutors' challenges facilitating students' argumentation. The majority of tutors had difficulty with facilitating students in the experimental group to engage in argumentation (*n* = 5). They reported that they did not have a clear idea about when and to what extent they should intervene in students' argumentation. This is reflected in one of the tutors' responses [Tutor 1]: "Whenever students expressed only claims without data or warrants, I could not ask each of them to say their own arguments again including the data and warrants, because I was concerned whether my frequent intervention might cause them to be reluctant to express their ideas." This tutor's challenge involves PBL tutors' difficulties with identifying the appropriate facilitation, which was found in previous studies (e.g., Azer, 2001; Hung, 2011). In addition, tutors experienced challenges with encouraging passive students to participate in the argumentation activity. Tutor 5 addressed, "Only two out of six students, about one third of a group, were enthusiastic about learning and cared about argumentation structures. . . . I was having concerns about how to guide students who were passive and did not care about argumentation to get into the argumentation activities." This shows differences in participating in group discussions during PBL between individual students (Hung, 2011; Ju et al., in press), which can give tutors concerns about how to balance the participation of every student in the group.

Perceptions of the workshop. For the workshop about argumentation provided for tutors, seven tutors perceived the workshop as being helpful for them to facilitate students' discussions during PBL. For example, Tutor 8 said in his interview, "The workshop helped my intervention in students' discussions. It [the workshop] guided me to focus more on what they [the students] were saying." Moreover, four tutors reported that the workshop assisted them in understanding concepts of argumentation. Tutor 6 commented, "Through the workshop, I got to know the importance of argumentation, which led me to help students with their lack of argumentation skills." However, only one tutor [Tutor 4] said that the workshop did not influence her own strategy when facilitating students' discussions, because she already had been trying to assist students with providing data or warrants when they only made claims, even before the workshop.

Utilization of the question prompts. Regarding the question prompts given to tutors, six tutors did not ask students these questions. Tutor 1 mentioned, "I did not use it [the question prompt]. I learned that the workshop's key point was to help students not present only claims. I was reflecting this. The question prompt included the key point, so I did not need to consult it [the question prompt]." Although the tutors did not directly use the questions as included in the prompt, they guided students' argumentation using their own contextual questions. For example, Tutor 6 addressed, "The question prompts included general questions, so I thought that it would be better to ask them [the students] specific questions, considering the contexts in which they had discussions and identifying what components of the arguments students were missing." Two tutors reported that they used the question prompts a few times during PBL sessions. One of them [Tutor 5] responded, "I referred to it [the question prompt] about two or three times when students' discussions seriously got stuck. . . . But, I was concerned whether I intervened in their discussions too much." These tutors' perceptions of the instruction on the structure of argumentation and question prompts (ISA-QP) indicate that compared to students, tutors found the workshop more helpful for guiding students' argumentation rather than for the question prompts.

Discussion

Enhanced the Quality of Students' Argumentation

The results of this study showed that using the instruction on the structure of argumentation and question prompts (ISA-QP) affected the quality of students' argumentation during the HDR process in PBL. This study found that students who received the ISA-QP produced more high-level arguments (Level 3 arguments) that included all three of the essential components (a claim, data, and a warrant) than those who did not receive the ISA-QP during the overall HDR phases.

In terms of each phase of HDR, significant differences in the frequency of the different levels of students' arguments between the control and experimental groups occurred in the hypothesis generation and inquiry strategy phases. This may be explained as the two phases required students to generate as many ideas as possible through creative and divergent thinking rather than other HDR phases (e.g., the diagnostic decision phase involves convergent thinking), and the experimental group might have paid more attention to providing justifications for their creative ideas according to the structure of argumentation for the two reasoning phases than the control group. However, during most phases of HDR, the experimental group constructed Level 1 arguments (claim only) more than Level 2 (claim with data) and Level 3 arguments (claim with data and warrant) like the control group did. One possible explanation for the finding may be that it was hard for the students to become used to constructing arguments, following the structure of argumentation in relation to each phase of HDR only during the two PBL courses, as some students and tutors pointed out in their interviews. This suggests that students will need more time and practice to adapt to the new approach of argumentation (including at least the three primary components in their arguments) during PBL sessions. The other possible explanation may be the students' insufficient knowledge for offering warrants, which could make them feel uncertain, resulting in being reluctant to provide warrants for their claims to a certain degree. In order for students to be more actively involved in the activity of producing and exchanging valid arguments, it will be necessary for them to recognize that PBL is the process of exploring unknown knowledge and to be comfortable with ambiguity (Barrows, 1996; Barrows & Tamblyn, 1980, Ju et al., in press). Ways to help them do so will be explored in further research.

Improvements in Students' Experiences with PBL

In addition to improving the quality of arguments elicited by students, this study found that students' argumentation activities with the help of the instruction on the structure of argumentation and question prompts (ISA-QP) enhanced the quality of students' experiences with PBL, which is concerned with the achievement of the goals of PBL.

Firstly, students should be encouraged to construct knowledge involving causal explanations of a given patient's problem, applying basic science knowledge to clinical contexts during PBL (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Hmelo-Silver & Barrows, 2008). In this study, we found that the structure of argumentation in relation to the HDR process guided students in retrieving, using, and learning basic science knowledge related to the patient's problem. Students in the experimental group made more endeavors to employ the knowledge of pathophysiological mechanisms for providing warrants to justify connections between their certain claims and the patient's clinical data than those in the control group, which could contribute to a higher frequency of arguments including a claim, data, and a warrant (Level 3 argument) produced by the experimental group than by the control group. Moreover, constructing arguments according to the structure of argumentation for the HDR processes stimulated students' systems thinking that helped to organize and structure their knowledge in terms of causal mechanisms involved in a patient's problem. The findings of this study suggest that promoting students' argumentation can facilitate students to learn and deepen their basic science knowledge that may be retrieved and used later for other clinical problems (Barrows, 1985, 1994; Barrows & Tamblyn, 1980) and to make a causal mental representation of a clinical case (Boshuizen & Schmidt, 1992; Woods, 2007).

Secondly, the PBL method expects students to foster their HDR skills (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Hmelo, 1998). Although students knew the HDR process by participating in PBL courses several times before, the workshop on the structure of argumentation and question prompts used (ISA-QP) for this study assisted the students in gaining better understandings of the aims of each HDR phase, steps of HDR, and important activities they need to perform according to each reasoning phase. This encouraged the students to identify what needed to be discussed for each phase of HDR and to be more engaged in each phase of HDR, which may have allowed them to generate focused statements. Also, reflection is an essential skill to guide students' own reasoning process (Barrows, 1985, 1994; Christensen, Jones, Higgs, & Edwards, 2008). Physicians need to continuously ponder their analysis of a patient's problem, their knowledge and skills, their decisions, and the like as the clinical reasoning process goes on (Barrows, 1985, 1994; Christensen et al., 2008). Argumentation coherent to the structure of argumentation for the HDR processes served as a means for students' reflections on the construction of arguments, which could help students organize their ideas or refine words in accordance with each HDR phase. This suggests that supporting students' argumentation during PBL can enable students to take a coherent approach to the HDR process.

Another important goal of PBL is that students should develop self-directed learning abilities to improve their medical knowledge and skills for solving problems that they may encounter in their future professional practices (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Hmelo-Silver, 2004). One component of self-directed learning skills is to identify personal or group learning needs through self-monitoring as the problem-solving process goes on (Barrows, 1985, 1994). This study found that as students in the experimental group engaged in argumentation according to the argument structures for the HDR processes, they monitored their arguments, recognized what knowledge is lacking or what areas obviously are not understood and need to be explored (learning goals), and formulated their learning goals more specifically to help them determine appropriate learning resources for dealing with the learning goals, more so than they did before they were provided with the instruction on the structure of argumentation and question prompts (ISA-QP). The other component of self-directed learning skills is to use properly available learning resources (Barrows, 1985, 1994; Knowles, 1975). For learning resources, students in both the control and experimental groups mostly employed their text books (e.g., Harrison's internal medicine book), but some students in the experimental group looked up knowledge or information to be studied in their text books as well as in current research articles so that they could produce more sound arguments with more contemporary information. Another component of self-directed learning skills is to implement appropriate learning strategies (Candy, 1991; Knowles, 1975). In this study, the students' argumentation activity influenced their learning strategies; the students in the experimental group tended to seek and study information in a manner of deep learning with respect to both "what" and "why" to apply the structure of argumentation to their arguments. Thus, enhancing students' argumentation during PBL would be more likely to foster their self-directed learning skills as one of the significant goals of PBL.

Improvements in Tutors' Experiences with PBL

Besides students' experiences with PBL, this study found that the instruction on the structure of argumentation and question prompts (ISA-QP) provided for tutors had an effect on tutors' experiences facilitating students' discussions during PBL sessions. PBL tutors are expected to become facilitators or guides for students' learning processes instead of disseminating information or knowledge to students (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Hmelo-Silver & Barrows, 2008; Maudsley, 1999), and the skill of the tutor is essential to the enhancement of the quality of PBL (Gijselaers & Schmidt, 1990; van Berkel & Dolmans, 2006). According to previous studies (e.g., Azer, 2001; Ju et al., in press), PBL tutors had a lack of understanding about the tutor's role; for example, some were not sure when and how to intervene in students' discussions during PBL. In this study, the workshop and question prompts for tutors helped the tutors identify the structure of argumentation in relation to the HDR processes as well as how to promote students' argumentation. This allowed them to facilitate students to keep involved in the HDR processes by monitoring, questioning, and providing constructive feedback on students' arguments according to the structure of argumentation, which could encourage the students to be aware of deficiencies in their arguments or knowledge and to produce quality arguments. This study suggests that tutors who have a clear understanding of argumentation for the HDR process can help students engage in argumentation, focusing on their role in guiding students' reasoning processes, rather than in acting as a primary source of information through appropriate instructional strategies, such as questioning.

Challenges Experienced by Students and Tutors

Although students in the experimental group and tutors had positive experiences with PBL during this study, they experienced several challenges during PBL sessions. For the students, they found it difficult to apply the argument structures for each phase of HDR and made claims without justification more than generated well-reasoned arguments, including all of the essential components (a claim, data, and a warrant), which may have been attributed to the students' change into a new habit of argumentation during the short period of this study. The students' challenges would be resolved through long-term implementation for enhancing students' argumentation in order for students to gradually get into the habit of building cogent arguments. In an effort to ease tutors' frustration in promoting students' argumentation, they need to be provided with tutor workshops or training programs to acquire specific skills (e.g., giving feedback or assessing students' argumentation) besides questioning or to learn how to manage group dynamics in PBL (Azer, 2005; Barrows, 1994; Dolmans, Wolfhagen, van der Vleuten, & Wijnen, 2001; Kaufman & Holmes, 1996). Also, in order to improve their skills to facilitate students' argumentation, it would be helpful to evaluate their performance of tutoring through a self-assessment or students' feedback.

Conclusion

Problem-based learning (PBL) involves the student-centered inquiry process of solving a problem (Barrows & Tamblyn, 1980; Schwartz, Mennin, & Webb, 2001), which requires students in a small group to present scientific explanations for a given problem, select and implement appropriate inquiry strategies for investigating the problem, and make decisions about solutions to the problem through argumentation. It is necessary to support medical students' argumentation that can help to construct coherent causal mechanisms of a patient's problem and systematically conduct the problem solving processes, which can empower their HDR skills. The findings of this study suggest that the instruction on the structure of argumentation and the question prompts (ISA-QP) in relation to each phase of HDR provided for medical students and PBL tutors can enhance the quality of students' arguments during HDR processes and the quality of experiences with PBL for students and tutors. Our study will provide insight into how to facilitate students' argumentation for the HDR process, how promoting argumentation contributes to students' pursuits of the major objectives of PBL—not only the development of HDR skills but also the acquisition of a solid knowledge base and improvement of self-directed learning skills—and how to assist PBL tutors in developing their skills to guide students' argumentation, focusing on students' learning processes.

Limitations and Suggestions for Future Research

This study has some limitations. First, this study used a small sample size of first-year preclinical students at one research site and limited clinical cases for the two PBL courses, which may lead to difficulty in generalizing this study's findings across different clinical cases and medical schools. Findings from our study need to be validated by a larger sample and extended to other clinical cases and possibly to other populations.

Second, our analysis of students' arguments was based on individual contributions explicitly ascribed to group discussions. In generating arguments subsequent to others' statements, some students might have omitted a certain component of an argument that was mentioned in previous statements, which was not reflected in the results of this study. But, identifying implicit components in students' arguments can depend on coders or reviewers, which may cause threats to the reliability. Future research should establish an analytical framework to keep track of the development of collaborative argument building for students in a small group, avoiding the threats to the reliability of the argument analysis.

Another limitation is that this current study focused on the effects of the workshop and question prompts on students' argumentation, but diverse factors might have affected students' argumentation activity; for example, students from different conditions might have had different prior knowledge, learning experiences, motivation for PBL, or personalities, and group dynamics might have played a role, as well. For future research, it will be interesting to investigate relationships between personal or group factors and the effects of the interventions on the quality of students' argumentation by using surveys or conducting interviews with students from the control and experimental groups.

In addition, students and tutors who were provided with the interventions reported that they faced challenges during PBL sessions, such as students' unnatural discussions and tutors' difficulty with facilitating students' balanced participation. Development of additional strategies to resolve the students' and tutors' challenges or frustrations would be suggested as future research.

References

Azer, S. A. (2001). Problem-based learning: Challenges, barriers and outcome issues. *Saudi Medical Journal*, *22*(5), 389–397.

Azer, S. A. (2005). Challenges facing PBL tutors: 12 tips for successful group facilitation. *Medical Teacher*, *27*(8), 676–681. doi:10.1080/01421590500313001

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years.* New York, NY: Springer.

Barrows, H. S. (1994). *Practice-based learning: Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. *New Directions for Teaching and Learning*, *1996*(68), 3–12. doi:10.1002/tl.37219966804

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York, NY: Springer.

Buckingham Shum, S. J., MacLean, A., Bellotti, V., & Hammond, N. V. (1997). Graphical argumentation and design cognition. *Human-Computer Interaction, 12*(3), 267–300.

Boeije, H. (2002). A purposeful approach to the constant comparative method in the analysis of qualitative interviews. *Quality & Quantity, 36*(4), 391–409.

Boshuizen, H. P., & Schmidt, H. G. (1992). On the role of biomedical knowledge in clinical reasoning by experts, intermediates and novices. *Cognitive Science, 16*(2), 153–184. doi:10.1207/s15516709cog1602_1

Candy, P. C. (1991). *Self-direction for lifelong learning.* San Francisco: Jossey-Bass

Cerbin, B. (1988). *The nature and development of informal reasoning skills in college students.* Retrieved from ERIC database (ED298 805).

Charmaz, K. (2014). *Constructing grounded theory* (2nd ed.). Thousand Oaks, CA: Sage.

Chin, C., & Osborne, J. (2010). Supporting argumentation through students' questions: case studies in science classrooms. *Journal of the Learning Sciences, 19*(2), 230–284. doi:10.1080/10508400903530036

Cho, K. L., & Jonassen, D. H. (2002). The effects of argumentation scaffolds on argumentation and problem solving. *Educational Technology Research and Development, 50*(3), 5–22. doi:10.1007/BF02505022

Christensen, N., Jones, M. A., Higgs, J., & Edwards, I. (2008). Dimensions of clinical reasoning capability. In Joy H., Mark, J., Stephen, L., & Nicole C (Eds.), *Clinical reasoning in the health professions* (3rd ed.) (pp. 101–110). Boston, MA: Butterworth-Heinemann.

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement, 20*(1), 37–46. doi:10.1177/001316446002000104

Cook, T. D., & Campbell, D. T. (1979). *Quasi-experimentation: Design and analysis issues for field settings.* Chicago, IL: Rand McNally.

Creswell, J. W. (2007). *Qualitative inquiry and research design: Choosing among five traditions* (2nd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches* (4th ed.). Thousand Oaks, CA: Sage

Dolmans, D. H., Wolfhagen, I. H., van der Vleuten, C. P., & Wijnen, W. H. (2001). Solving problems with group work in problem-based learning: Holding on to the philosophy. *Medical Education, 35*, 884–889. doi:10.1046/j.1365-2923.2001.00915.x

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287–312. doi:10.1002/(SICI)1098-237X(200005)84:3<287::AID-SCE1>3.0.CO;2-A

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38*(1), 39–72. doi:10.1080/03057260208560187

Elstein, A. S. (1995). Clinical reasoning in medicine. In J. Higgs & M. A. Jones (Eds.), *Clinical reasoning in the health professions* (pp. 49–59). Boston, MA: Butterworth-Heinermann.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education, 88*(6), 915–933. doi:10.1002/sce.20012

Fisher, R. S. (1970). *Statistical methods for research workers* (14th ed.). Edinburgh: Oliver & Boyd.

Frederiksen, C. H. (1999). Learning to reason through discourse in a problem-based learning group. *Discourse Processes, 27*(2), 135–160. doi:10.1080/01638539909545055

Freeman, J. V., & Julious, S. A. (2007). The analysis of categorical data. *Scope, 16*(1), 18–21.

Gagné, R. M., Wager, W. W., Golas, K. C., & Keller, J. M. (2005). *Principles of instructional design* (5th ed.). Belmont, CA: Wadsworth/Thomson Learning.

Gijselaers, W.H. & Schmidt, H.G. (1990). The development and evaluation of a causal model of problem-based learning. In Z. Norman, H.G. Schmidt, & E. Ezzat (Eds.), *Innovation in medical education: An evaluation of its present status* (pp. 95–113). New York, NY: Springer Publishing.

Glaser, B. G., & Strauss, A. L. (1967). The constant comparative method of qualitative analysis. In B. G. Glaser & A. L. Strauss, *The discovery of grounded theory: Strategies for qualitative research* (pp. 101–115). Hawthorne, NY: Aldine Publishing Company.

Greene, J. C. (2007). *Mixed methods in social inquiry*. San Francisco: Jossey-Bass.

Graesser, A. C., Baggett, W., & Williams, K. (1996). Question-driven explanatory reasoning. *Applied Cognitive Psychology, 10*(Special), 17–31. doi:10.1002/(SICI)1099-0720(199611)10:7%3C17::AID-ACP435%3E3.0.CO;2-7

Hewson, M. G., & Ogunniyi, M. B. (2010). Argumentation-teaching as a method to introduce indigenous knowledge into science classrooms: Opportunities and challenges. *Cultural Studies of Science Education*, *6*(3), 679–692. doi:10.1007/s11422-010-9303-5

Higgs, J., & Jones, M. A. (Eds.). (1995). *Clinical reasoning in the health professions*. Boston, MA: Butterworth-Heinermann.

Hmelo, C. E. (1998). Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. *The Journal of the Learning Sciences, 7*(2), 173–208. doi:10.1207/s15327809jls0702_2

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266. doi:10.1023/B:EDPR.0000034022.16470.f3

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction, 26*(1), 48–94. doi:10.180/07370000701798495

Huang, C.-J., Chen, H.-X., & Chen, C.-H. (2009). Developing argumentation processing agents for computer-supported collaborative learning. *Expert Systems with Applications, 36*(2), 2615–2624. doi:10.1016/j.eswa.2008.01.036

Hung, W. (2011). Theory to reality: A few issues in implementing problem-based learning. *Educational Technology Research and Development*, *59*(4), 529–552. doi:10.1007/s11423-011-9198-1

Jiménez-Aleixandre, M. P., & Rodriguez, A. B. (2000). “Doing the lesson” or “Doing science”: Argument in high school genetics. *Science Education, 84*(6), 757–792.

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments.* New York, NY: Routledge.

Jonassen, D. H., & Kim, B. (2009). Arguing to learn and learning to argue: Design justifications and guidelines. *Educational Technology Research and Development*, *58*(4), 439–457. doi:10.1007/s11423-009-9143-8

Ju, H., Choi, I., Rhee, B., & Lee, J. (in press). Challenges experienced by Korean medical students and tutors during problem-based learning: A cultural perspective. *The Interdisciplinary Journal of Problem-Based Learning.*

Kaufman, D. M., & Holmes, D. (1996). Tutoring in problem-based learning: Perceptions of teachers and students. *Medical Education, 30*(5), 371–377. doi:10.1111/j.1365-2923.1996.tb00850.x

Knowles, M. S. (1975). *Self-directed learning: A guide for learners and teachers*. New York: Association Press.

Kuhn, D. (1992). Thinking as argument. *Harvard Educational Review, 62*(2), 155–178. doi:10.4324/9780203435854_chapter_7

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1). 159–174. doi:10.2307/2529310

Larson, B. E., & Keiper, T. A. (2002). Classroom discussion and threaded electronic discussion: Learning in two arenas. *Contemporary Issues in Technology and Teacher Education [Online serial], 2*(1), 45–62.

Larson, L. R., & Lovelace, M. D. (2013). Evaluating the efficacy of questioning strategies in lecture-based classroom environments: Are we asking the right questions? *Journal on Excellence in College Teaching, 24*(1), 105–122.

Lawson, A. E. (2003). The nature and development of hypothetico-predictive argumentation with implications for science teaching. *International Journal of Science Education, 25*(11), 1387–1408. doi:10.1080/0950069032000052117

Maudsley, G. (1999). Roles and responsibilities of the problem based learning tutor in the undergraduate medical curriculum. *British Medical Journal, 318*(7184), 657–661. doi:10.1136/bmj.318.7184.657

McNeill, K. L., & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on k-12 teachers. *Science Education, 97*(6), 937–972. doi:10.1002/sce.21081

McNeill, K. L., & Krajcik, J. (2007). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In M. Lovett & P. Shah (Eds.), *Thinking with data* (pp. 233–265). New York: Taylor & Francis.

McNeill, K., & Krajcik, J. (2008). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching, 45*(1), 53–78. doi:10.1002/tea.20201

McNeill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences, 15*(2), 153–191. doi:10.1207/s15327809jls1502_1

McNeill, K. L., & Pimentel, D. S. (2010). Scientific discourse in three urban classrooms: The role of the teacher in engaging high school students in argumentation. *Science Education, 94*(2), 203–229. doi:10.1002/sce.20364

Merriam, S. B. (2009). *Qualitative research: a guide to design and implementation* (3rd ed.). San Francisco, CA: Jossey-Bass.

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education, 21*(5), 553–576. doi:10.1080/095006999290570

Nussbaum, E. M. (2011). Argumentation, dialogue theory, and probability modeling: Alternative frameworks for argumentation research in education. *Educational Psychologist*, *46*(2), 84–106. doi:10.1080/00461520.2011.558816

Oh, S., & Jonassen, D. H. (2007). Scaffolding online argumentation during problem solving. *Journal of Computer Assisted Learning, 23*(2), 95–110. doi:10.1111/j.1365-2729.2006.00206.x

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching, 41*(10), 994–1020. doi:10.1002/tea.20035

Patton, M. Q. (2015). *Qualitative research & evaluation methods* (4th ed.). Thousand Oaks, CA: Sage.

Patel, V. L., Arocha, J. F., & Zhang, J. (2005). Thinking and reasoning in medicine. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 727–750). New York, NY: Cambridge University Press.

Patel, V. L., Evans, A. E., & Groen, G. J. (1989). Biomedical knowledge and clinical reasoning. In D. A. Evans & V. L. Patel (Eds.), *Cognitive science in medicine: Biomedical modeling* (pp. 53–112). Cambridge, MA: MIT Press.

Ruona, W. (2005). Analyzing qualitative data. In Richard A. Swanson & Elwood F. Holton (Eds.), *Research in organizations: Foundations and methods of inquiry* (pp. 223–263). San Francisco, CA: Berrett-Koehler.

Sanders, J. A., & Wiseman, R. L. (1994). Does teaching argumentation facilitate critical thinking?. *Communication Reports, 7*(1), 27–35. doi:10.1080/08934219409367580

Sampson, V., & Blanchard, M. (2012). Science teachers and scientific argumentation: Trends in views and practice. *Journal of Research in Science Teaching, 49*(9), 1122–1148.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2–3), 235–260. doi:10.1080/09500690500336957

Toth, E. E., Suthers, D. D., & Lesgold, A. M. (2002). “Mapping to know”: The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education, 86*(2), 264–286. doi:10.1002/sce.10004

Schwartz, P., Mennin, S., & Webb, G. (Eds.). (2001). *Problem-based learning: Case studies, experience and practice.* London, UK: Kogan page.

Schwarz, B. B., Neuman, Y., & Gil, J. (2003). Construction of collective and individual knowledge in argumentative activity. *The Journal of the Learning Sciences*, *12*(2), 219–256. doi:10.1207/S15327809JLS1202_3

Siegel, H. (1995). Why should educators care about argumentation? *Informal Logic, 17*(2), 159–176.

Suthers, D., & Hundhausen, C. (2003). An empirical study of the effects of representational guidance on collaborative learning processes. *Journal of the Learning Sciences, 12*(2), 183–219. doi:10.1207/S15327809JLS1202_2

Toulmin, S. (1958). *The uses of argument.* Cambridge: Cambridge University Press.

Toulmin, S. (2003). *The uses of argument.* Cambridge: Cambridge University Press.

van Berkel, H. J. M., & Dolmans, D. H. J. M. (2006). The influence of tutoring competencies on problems, group functioning and student achievement in problem-based learning. *Medical Education, 40*(8), 730–736. doi:10.1111/j.1365-2929.2006.02530.x

van Eemeren, F. H., Grootendorst, R., Henkemans, F. S., Blair, J. A., Johnson, R. H., Krabbe, E. C. W., … Zarefsky, D. (1996). *Fundamentals of argumentation theory: A handbook of historical backgrounds and contemporary developments.* Mahwah, NJ: Lawrence Erlbaum Associates.

Veerman, A., Andriessen, J., & Kanselaar, G. (2002). Collaborative argumentation in academic education. *Instructional Science, 30*(3), 155–186.

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

CHAPTER 5

CONCLUSION

Improving the clinical reasoning of physicians is an important goal for ensuring the safety of patients, because doing so can reduce diagnostic errors that contribute to patient mortality or morbidity (Croskerry, 2009). Therefore, it is imperative for medical students in their early medical training to foster their clinical reasoning skills. Problem-based learning (PBL) has been implemented in undergraduate medical programs to enable medical students to develop hypothetico-deductive reasoning (HDR) that can provide them with an appropriate structure for medical problem solving (Barrows, 1985, 1994; Groves, 2007; Patel, Arocha, & Zhang, 2005). In PBL, medical students work in small groups (Barrows, 1985, 1994; Barrows & Tamblyn, 1980), and their argumentation is central to problem solving (Jonassen, 2011).

The aim of this dissertation was to find ways to enhance medical students' argumentation during the hypothetico-deductive reasoning (HDR) process in problem-based learning (PBL). Toulmin's (1958, 2003) argumentation model and Barrows' (1994) model of the clinical reasoning process guided the development of a conceptual framework, the structure of argumentation, including three essential components of an argument (a claim, data, and a warrant), in relation to each phase of HDR. The conceptual framework presented in Chapter 2 was employed in the two subsequent studies, serving as a means for analyzing and assessing medical students' argumentation during HDR processes in PBL (Chapter 3) and a guide for the design of instruction on the structure of argumentation and question prompts (ISA-QP) for promoting medical students' argumentation (Chapter 4).

The study described in Chapter 3 was conducted to assess Korean medical students' argumentation during HDR processes in PBL. Previous research found that Korean medical students and PBL tutors encountered challenges during PBL sessions, such as students' anxiety about uncertain knowledge and tutors' lack of understanding about a tutor's role (Ju, Choi, Rhee, & Lee, in press). Their challenges or frustrations may make it difficult to actively engage students in argumentation during PBL, which may discourage them from improving their HDR abilities. This assumption led to the undertaking of this research that examines Korean medical students' argumentation in PBL. Arguments constructed by two small groups of seven to eight first-year preclinical students during PBL sessions were analyzed using the conceptual framework presented in Chapter 2 and a coding scheme that included four different types of argumentation (incomplete, claim only, claim with data, and claim with data and warrant). The results indicated that the students predominantly generated arguments, including only claims without any justifications (data or warrants), during HDR processes, which suggested the need for instructional strategies to promote students' argumentation.

In Chapter 4, the study examined the effects of instruction on the structure of argumentation and question prompts (ISA-QP) on medical students' argumentation during HDR processes in PBL. The ISA-QP was developed based on the conceptual framework (Chapter 2) and provided to first-year preclinical students and PBL tutors. The quantitative analysis of students' arguments revealed that students who received the ISA-QP produced more high-level arguments than those who did not and the quality of argumentation between the control and experimental groups significantly differed during overall HDR phases and the hypothesis generation and inquiry strategy phases. According to analyses of the interviews with students from the experimental group and the tutors, the argumentation activities according to the structure of argumentation for the HDR process, benefitted the quality of students' experiences with PBL; however, some of the students reported challenges with applying the structure of argumentation to their argument building. For tutors, they found the ISA-QP helpful for guiding them in facilitating students' argumentation during PBL, but the majority of the tutors still felt concerned about their intervention in students' group discussions. These results suggest the need for additional strategies to resolve the students' and tutors' challenges experienced during PBL.

This dissertation study explored the structure of argumentation with respect to the HDR process and demonstrated the potential of the instruction on the structure of argumentation and question prompts (ISA-QP) for improving the quality of students' argumentation and for enriching the quality of their experiences with PBL, not only students' engagement of HDR but also the application of basic science knowledge to clinical contexts and development of self-directed learning skills.

Limitations and Future Research Directions

Given this dissertation study is an initial step for enhancing medical students' argumentation during PBL, there are several limitations and issues that need to be considered in future studies. Firstly, the structure of argumentation in relation to each phase of HDR included three primary components of an argument, *a claim, data, and a warrant*. Although the soundness of arguments essentially depends on data for supporting claims and warrants for justifying connections between claims and data, more sophisticated arguments may entail additional component(s), *a backing, a rebuttal, or a qualifier* (Toulmin, 1958, 2003). For example, arguments that include a backing in addition to a claim, data, and a warrant are deemed more valid and reliable, since the backing provides a rationale for the warrant (Toulmin, 1958, 2003). Assessing the quality of students' argumentation only based on the three basic components of an argument may make it difficult to understand students' abilities to corroborate the validity and reliability of the data and warrant presented or the applicability or appropriateness of the warrant, simplifying their arguments. Argumentation in medical contexts involves evidence-based medicine that requires skills of accessing contemporary information and evaluating the robustness of the information (Dickinson, 1998; Sackett, Rosenberg, Gray, Haynes, & Richardson, 1996; Upshur & Colak, 2003), which may need further supports for claims, such as backings for warrants, in arguments (Dickinson, 1998; Upshur & Colak, 2003). More reasonable and justifiable argumentation in the clinical reasoning process can be based on establishing the credibility and validity of the data and warrant by seeking information related to the clinical problem being explored from available various resources, assessing the quality and relevance of the information, and applying the newly obtained information into clinical reasoning processes in terms of evidence-based practice (Dickinson, 1998; Lusardi, Levangie, & Fein, 2002; Upshur & Colak, 2003). Thus, the current structure of argumentation for the HDR process will need further elaboration and validation efforts toward capturing students' skills of more complex argumentation and evidence-based approaches to practice.

Secondly, our analytical framework used for assessing students' argumentation may need further revision from the perspective of collaborative argument construction. Students can build their own arguments on another person's statements during group discussions. However, the analysis of arguments in this research was focused on whether each of the students in a small group completed an argument, which might not have sufficiently reflected students' actual argumentation skills or thinking processes in the context of PBL, where students analyze a patient's case and construct arguments together (Barrows, 1985, 1994; Barrows & Tamblyn, 1980; Hmelo-Silver & Barrows, 2008). For example, when a student generated his or her own claim based on data mentioned by another person but did not explicitly state the data, the argument was regarded as a "claim only" not a "claim with data." Thus, a modification of the analytical framework may be needed to encompass the structure of collaborative argumentation and detect the quality of group discussion and students' thinking processes within a dynamic sequence of conversational exchanges in PBL.

Thirdly, the research was conducted at a single medical school in one region of Korea with first-year preclinical students for certain PBL courses. To enhance the generalizability of the findings, further studies may be conducted across different regions, institutions, PBL courses, and grades (second-year preclinical or clinical students).

Lastly, while the combination of instruction on the structure of argumentation and question prompts was used as a strategy for promoting students' argumentation, which strategy was more effective between the instruction and question prompts in the quality of students' argumentation has not been conclusively validated. Although students in the experimental group reported in their interviews that they mostly employed question prompts and hardly referred to the workshop material during PBL sessions, it cannot be enough to note that the question prompts were a more effective strategy for supporting their argumentation activities. Thus, it would be necessary that future studies investigate comparisons of the quality of students' arguments and experiences with argumentation activities among providing students with instruction on the structure of argumentation, question prompts, or a combination of the two.

References

Barrows, H. S. (1985). *How to design a problem-based curriculum for the preclinical years.* New York, NY: Springer.

Barrows, H. S. (1994). *Practice-based learning: Problem-based learning applied to medical education*. Springfield, IL: Southern Illinois University.

Barrows, H. S., & Tamblyn, R. M. (1980). *Problem-based learning: An approach to medical education*. New York, NY: Springer.

Croskerry, P. (2009). A universal model of diagnostic reasoning. *Academic Medicine, 84*(8), 1022–1028. doi:10.1097/ACM.0b013e3181ace703

Dickinson, H. D. (1998). Evidence-based decision-making: An argumentative approach. *International Journal of Medical Informatics, 51*(2–3), 71–81. doi:10.1016/S1386-5056(98)00105-1

Groves, M. (2007). The diagnostic process in medical practice: The role of clinical reasoning. In E. M. Vargios (Ed.), *Educational psychology research focus* (pp. 133–184). New York, NY: Nova Science Publisher.

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction, 26*(1), 48–94. doi:10.180/07370000701798495

Jonassen, D. H. (2011). *Learning to solve problems: A handbook for designing problem-solving learning environments.* New York, NY: Routledge.

Ju, H., Choi, I., Rhee, B., & Lee, J. (in press). Challenges experienced by Korean medical students and tutors during problem-based learning: A cultural perspective. *The Interdisciplinary Journal of Problem-Based Learning.*

Lusardi, M., Levangie, P., & Fein, B. (2002). A problem-based learning approach to facilitate evidence-based practice in entry-level health professional education. *Journal of Prosthetics & Orthotics (JPO), 14*(2), 40–50. doi:10.1097/00008526-200206000-00005

Patel, V. L., Arocha, J. F., & Zhang, J. (2005). Thinking and reasoning in medicine. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge handbook of thinking and reasoning* (pp. 727–750). New York, NY: Cambridge University Press.

Sackett, D. L., Rosenberg, W. C., Gray, J. M., Haynes, R. B., & Richardson, W. S. (1996). Evidence based medicine: What it is and what it isn't. *BMJ: British Medical Journal, 312*(7023), 71–72. doi:10.1136/bmj.312.7023.71

Toulmin, S. (1958). *The uses of argument.* Cambridge: Cambridge University Press.

Toulmin, S. (2003). *The uses of argument.* Cambridge: Cambridge University Press.

Upshur, R.E.G., & Colak, E. (2003). Argumentation and evidence. *Theoretical Medicine and Bioethics, 24*(4), 283–299.

APPENDIX A.1

WORKSHOP PLAN FOR STUDENTS AND TUTORS

Event	Instructional Strategy	Facilitator(F) or Learner(L) Action	Media
Gain Attention	**[For students/ tutors]** • Describe the definition and purposes of argumentation	**F:** Present the definition and purposes of argumentation **L:** Identify the definition and importance of argumentation	▪ PowerPoint slide
Objective	**[For students/ tutors]** • Inform learners of the learning objective for this workshop	**F:** State a learning objective for this workshop	
Prior Knowledge	**[For students/ tutors]** • Identify the importance of argumentation in PBL	**F:** Ask about a main activity and goal of PBL **L:** Think about the major goal of PBL (clinical reasoning) and the importance of argumentation in PBL	▪ PowerPoint slide
Content	**[For students/ tutors]** • Describe components of argumentation	**F:** Present components (claim, data, warrant, backing, rebuttal, and qualifier) of argumentation **L:** Identify components of argumentation with examples of an argument, including the components	▪ Lecture ▪ PowerPoint slides ▪ Handout I: The structure of argumentation ▪ Discussion (Appendices A.2 & 3)
	• Provide statistical results about the types of medical students' arguments generated during PBL sessions	**L:** Identify students' lack of generating arguments, including claims, data, and warrants, during PBL sessions	▪ PowerPoint slide ▪ Discussion
Guided Practice	**[For students/ tutors]** • Identify HDR processes and the structure of argumentation in relation to each process of HDR	**F:** Provide an example of an argument that can be generated during each process of	▪ PowerPoint slides ▪ Handout II: The structure

		HDR, and ask learners to divide each argument into the three components of argumentation **L:** Divide each argument into the three components of argumentation (claims, data, and warrants)	of argumentation in the HDR process (Appendices A.2 & 3)
Independent Practice	**[For students]** • Each learner evaluates the given arguments	**L (Students):** Identify the missing components of argumentation in given arguments, and write complete arguments using an argument diagram **F:** Give learners assistance if needed	▪ Worksheet I: Activity I- The structure of argumentation in the HDR process (Appendix A.2)
	[For tutors] • Each learner evaluates the given arguments and thinks about questions for facilitating students to construct complete arguments	**L (Tutors):** Identify the missing components of argumentation in given arguments, and write questions to be asked as a tutor for facilitating students to complete arguments **F:** Give learners assistance if needed	▪ Worksheet I: Activity-The structure of argumentation in the HDR process (Appendix A.3)
Feedback	**[For students/ tutors]** • Provide an opportunity for checking his/her own answers	**F:** Present model answers **L:** Share his/her own answers and check his/her own answers according to the model answers	▪ PowerPoint slides
Assessment	**[For students]** • Each learner generates arguments and reviews his/her peer's arguments	**L:** Construct his/her own arguments to answer given questions **L:** Review his/her peer's arguments using a peer review checklist **F:** Provide important considerations for generating arguments during group discussions in PBL	▪ Worksheet II: Activity II- Argumentation practice (Appendix A.2) and Peer review checklist (Appendix A.2) ▪ Discussion
Closure	**[For students/tutors]** • Provide question prompts to be used during PBL sessions	**F:** Give a handout including question prompts that can guide argumentation during group discussions in PBL and, guide them in how to use it **L:** Ask questions about the question prompts	▪ Handout III: Question prompts for students (Appendix B.1)/ for tutors (Appendix B.2)

APPENDIX A.2

WORKSHOP FOR STUDENTS

THE STRUCTURE OF ARGUMENTATION

- *Argumentation* refers to the process of constructing ideas and providing justifications for the ideas
    - Components of argumentation

      (1) Claim: An expression of the position that is advanced in an argument

      (2) Data (Evidence): Factual information to provide support for the claim

      (3) Warrant: Reasons that justify the connection between the data and the claim

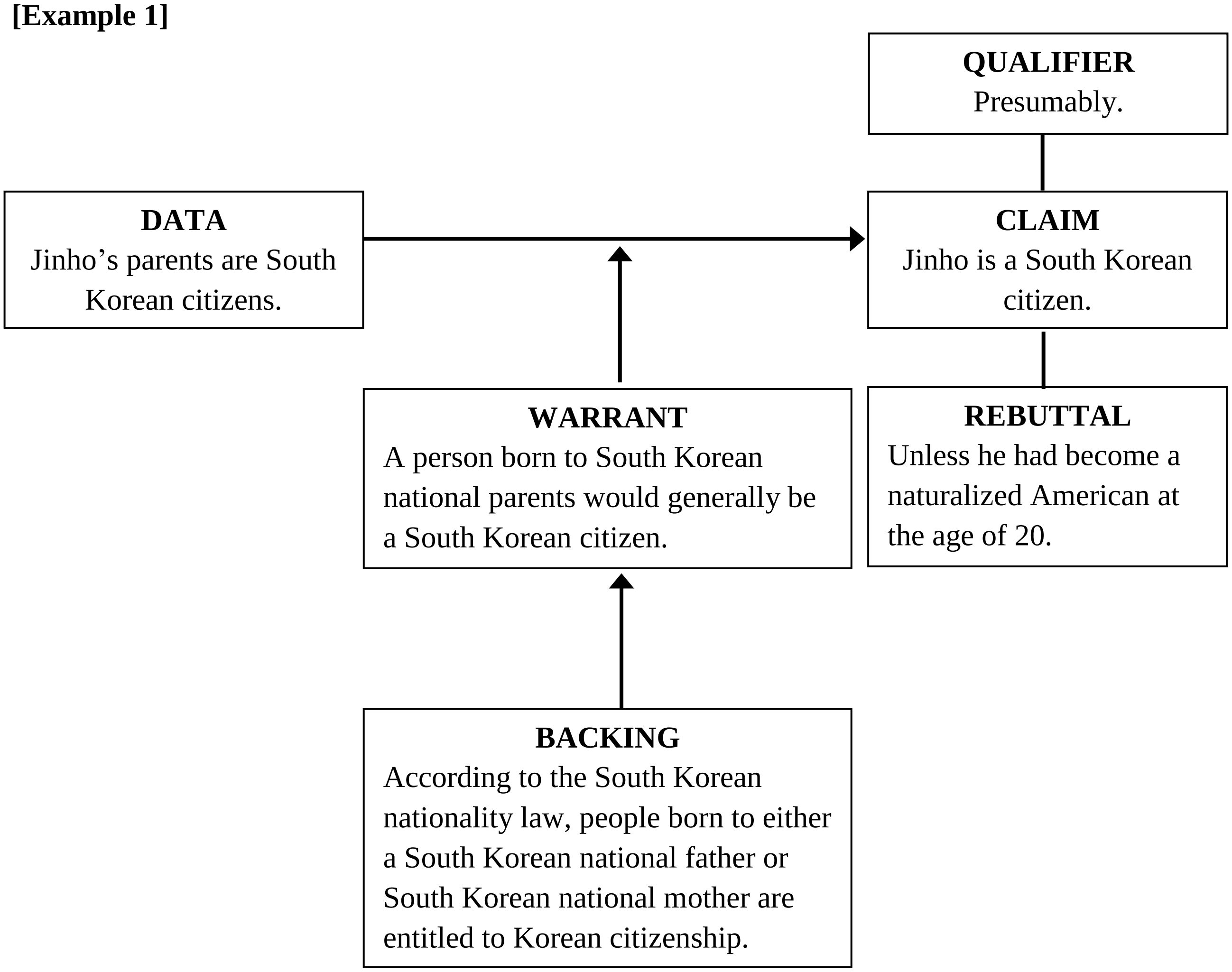
      (4) Backing: Statements to support the warrant

      (5) Rebuttal: Exceptions or limitations to the claim

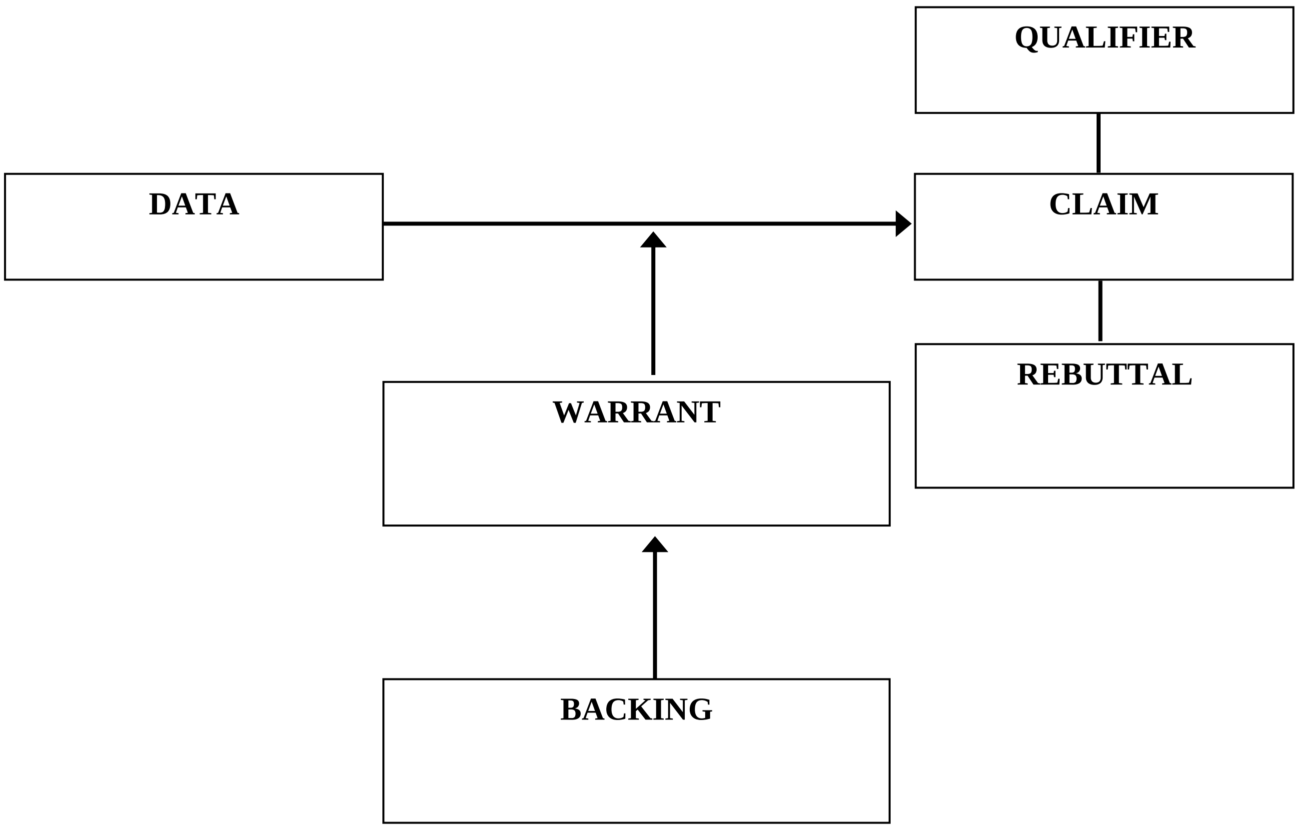
      (6) Qualifier: Words or phrases to express limited certainty of the claim (e.g., perhaps)

      **** The claim, data, and warrant are essential components of an argument!***

[Example 1]



[Example 2] Yuri's bedroom is probably on fire, because smoke is pouring out of Yuri's bedroom. Smoke is a primary sign of fire, since fires generally produce smoke. Unless the smoke is a product of a chemical reaction, it may not be enough to say that her bedroom is on fire.

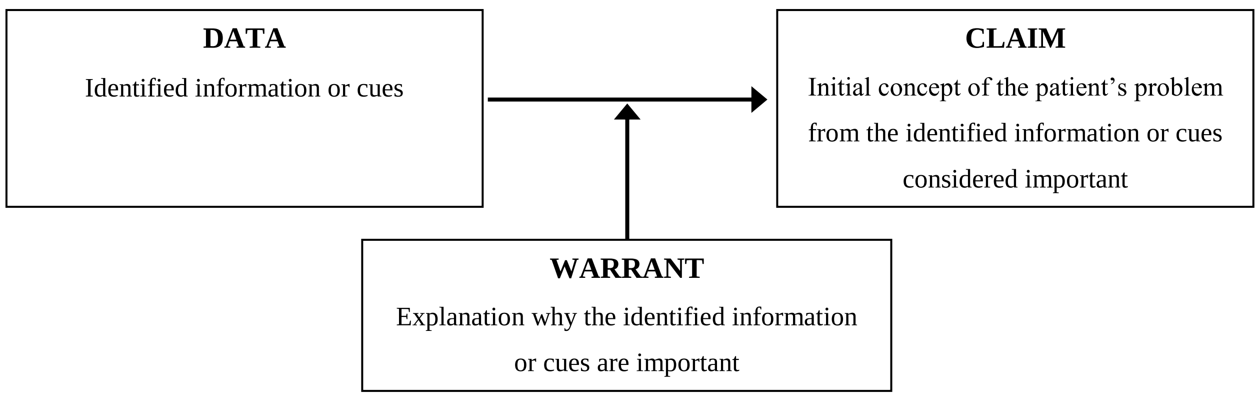


THE STRUCTURE OF ARGUMENTATION IN

THE HYPOTHETICO-DEDUCTIVE REASONING PROCESS

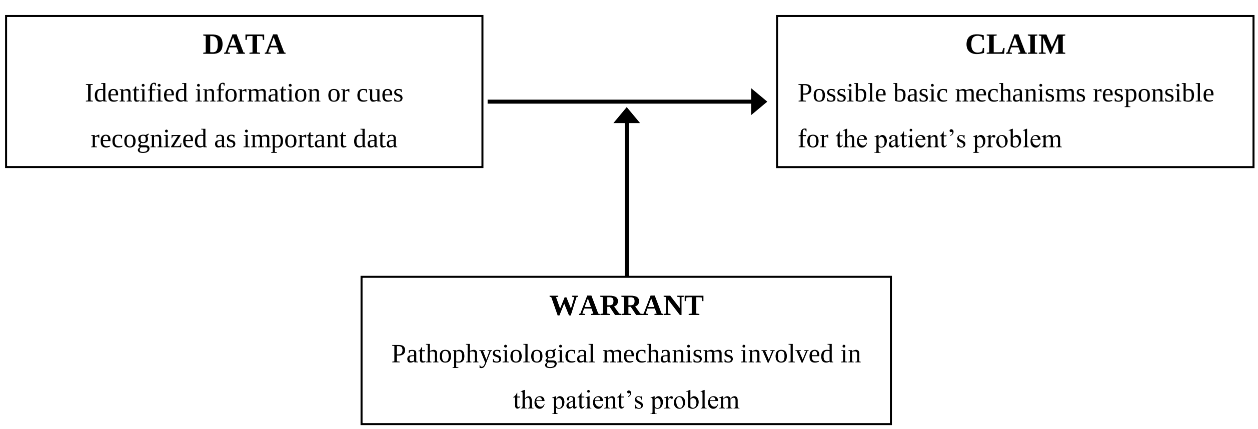
**** The essential components of an argument, <u>claim, data, and warrant,</u> should be included!***

<u>Phase 1: Problem Framing</u>



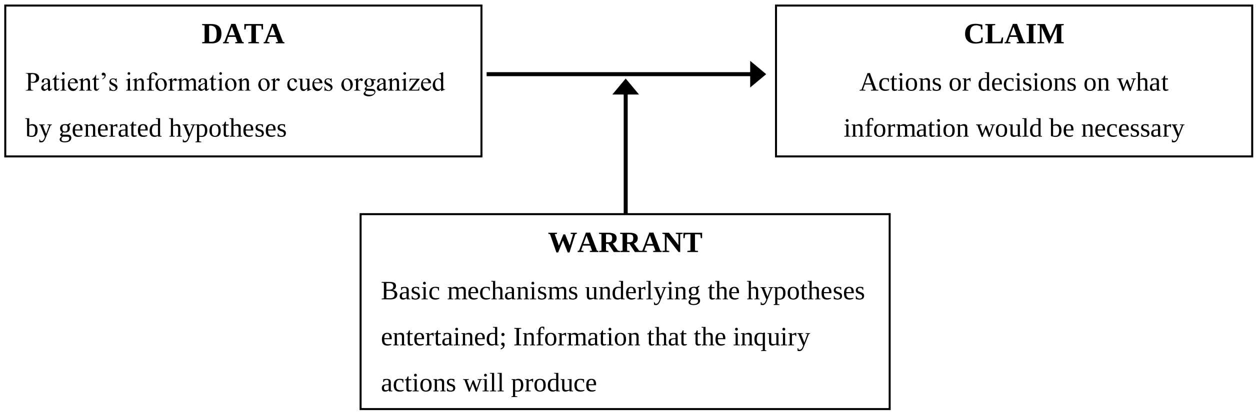
[Example] The patient is pale and vomiting fresh blood **<u>(Data)</u>**. She has a history of vomiting fresh blood mixed with food **<u>(Warrant)</u>**, so I think her chief complaint is hematemesis **<u>(Claim)</u>**.

<u>Phase 2: Hypothesis Generation</u>



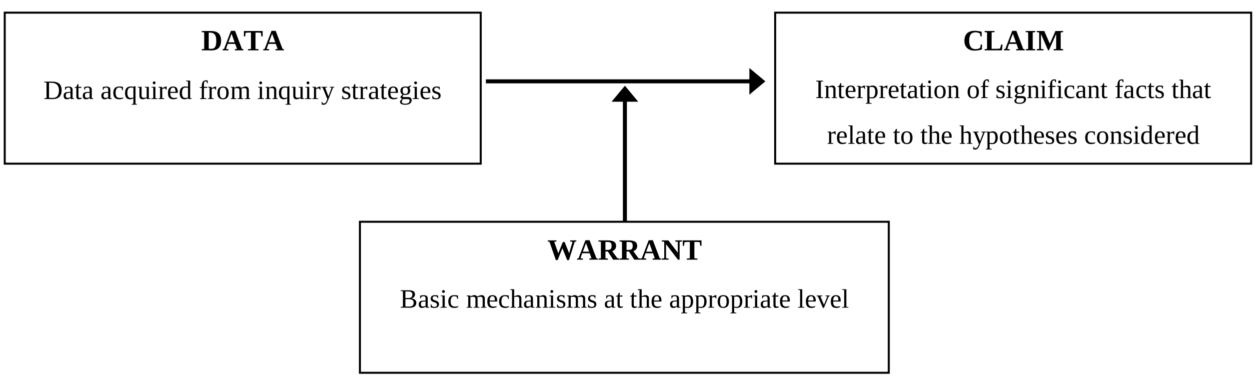
[Example] I think that the patient may have a decrease in the blood supply to her brain **<u>(Claim)</u>**, because her complaints are pallor and a loss of consciousness **<u>(Data)</u>**. A decrease in the blood supply to the brain can cause pallor and a lack of oxygen and nutrients supplied to the brain, which results in a loss of consciousness **<u>(Warrant)</u>**.

Phase 3: Inquiry Strategy



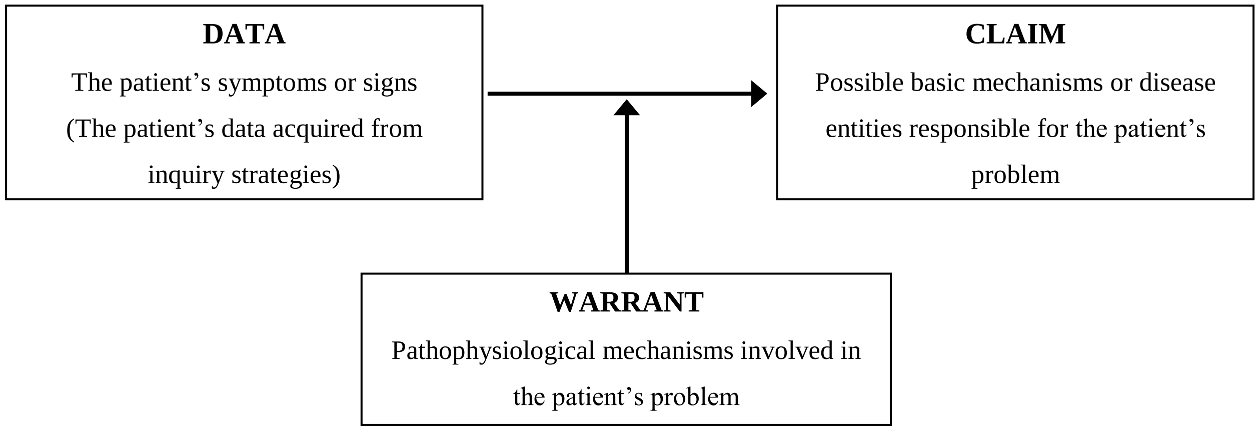
[Example] I think a CBC [complete blood count] would be necessary **(Claim)**, because the patient may have bleeding in her upper GI tract **(Data)**. The hematocrit is used to measure the percentage of the volume of whole blood that is made up of red blood cells, which helps to assess the extent of significant blood loss **(Warrant)**.

Phase 4: Data Analysis/Synthesis



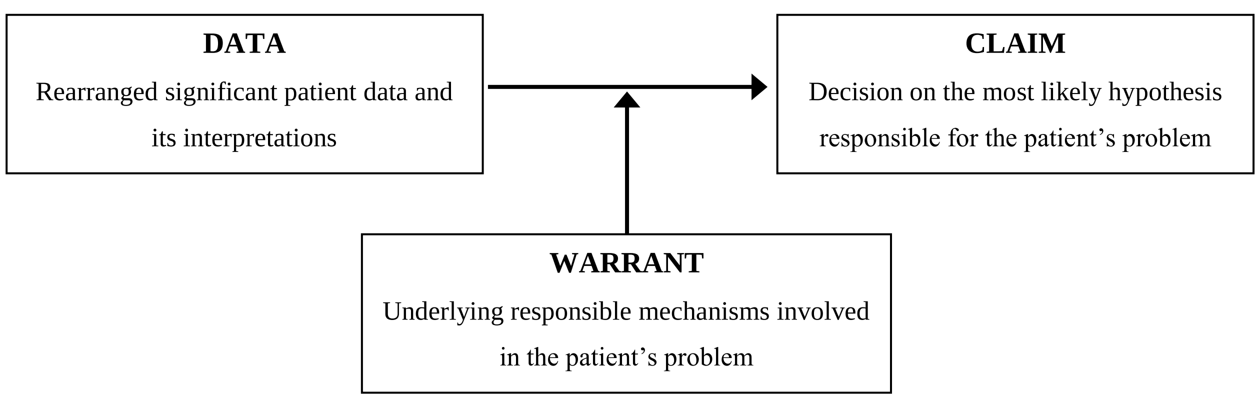
[Example] Like multi-organ failure, kidney failure is likely to occur **(____)** because of hematuria **(____)**. Since blood supply dysfunction and hypoxia were seen in the patient, they can result in kidney failure, which can cause blood in the urine **(____).**

Phase 5: Hypothesis Regeneration (* Replicable until arriving at Diagnostic Decision)



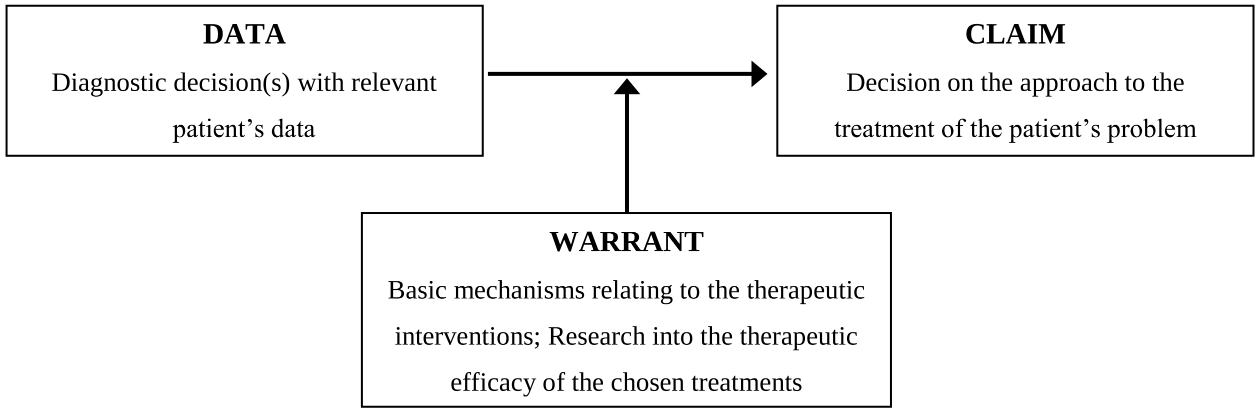
[Example] Lower gastrointestinal tract bleeding is the most likely among our hypotheses **(____)**. The patient has a history of a large amount of blood in her stool, is in a semi-coma, and has a blood pressure of 70/40mmHg **(____)**. Blood loss leads to reduced cardiac output, which decreases cerebral blood volume and oxygen supplies to the central nervous system [CNS], which disrupts the function of the CNS, resulting in a loss of consciousness **(____)**.

Phase 6: Diagnostic Decision



[Example] The patient's chief complaint is vomiting, and as results of the endoscopy, ulcerative lesions in the duodenum and gastric outlet obstructions were found **(____)**. Regions around the ulcers are swollen, which can cause gastric outlet obstruction, which in turn can result in vomiting **(____)**. Thus, I think the most likely diagnosis is a duodenal ulcer **(____).**

Phase 7: Therapeutic Decision



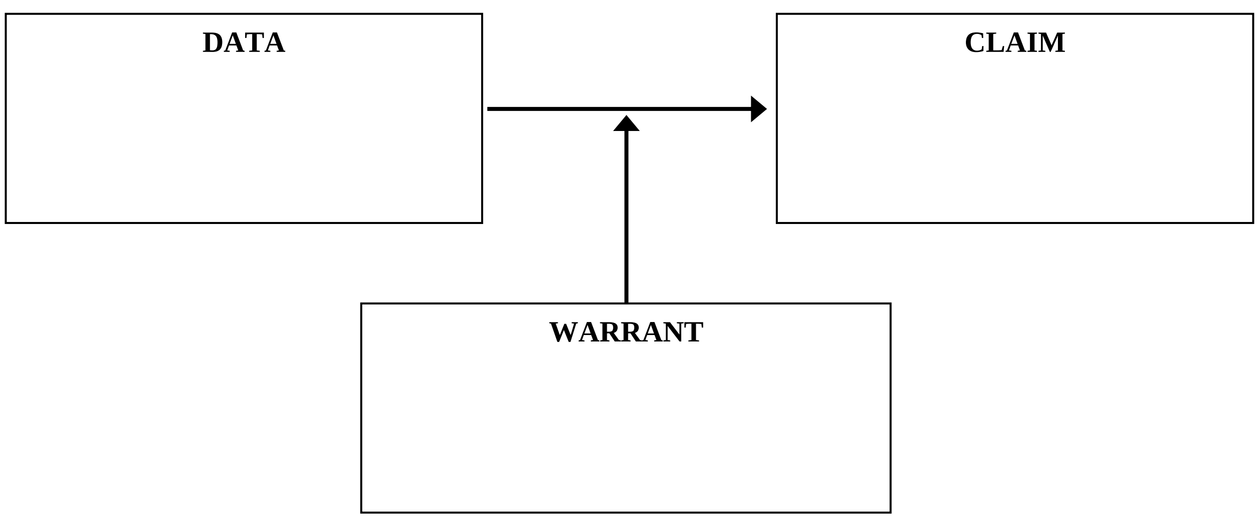
[Example] The patient's diagnosis is SAH [subarachnoid hemorrhage] **(____)**. It may be necessary to provide the patient with mannitol to reduce the ICP [intracranial pressure] **(____)**. An increase in the ICP is caused by bleeding, and mannitol cannot cross the blood-brain barrier, that will osmotically dehydrate the brain, which will cause water to move from the brain tissue into the blood vessels, which in turn will lower cerebrospinal fluid pressure resulting in decreased ICP **(____).**

ACITIVITY I: THE STRUCTURE OF ARGUMENTATION IN THE HYPOTHETICO-DEDUCTIVE REASONING PROCESS

The following statements are arguments generated during each process of clinical reasoning about the following patient's case. Please evaluate each of the statements using an argument diagram form. If there is any missing component(s) of argumentation in the statements, please note the missing one(s), and write a complete argument, including the three components of argumentation (a claim, data, and a warrant).

[Case] Ms. Hong, 48 years old, came into a hospital. She feels lethargic, sometimes has a fever, and has pain in her mouth. She said that she often had swollen gums, canker sores, and bruises on her arms and body.

1. **<u>Problem Framing: What are the patient's chief complaints?</u>**
   I think that the patient's chief complaints are fever, oral ulcers, and bruises.



The patient's case was adapted from a patient's case used for an example of a modified essay question (MEQ) at Inje University College of Medicine.

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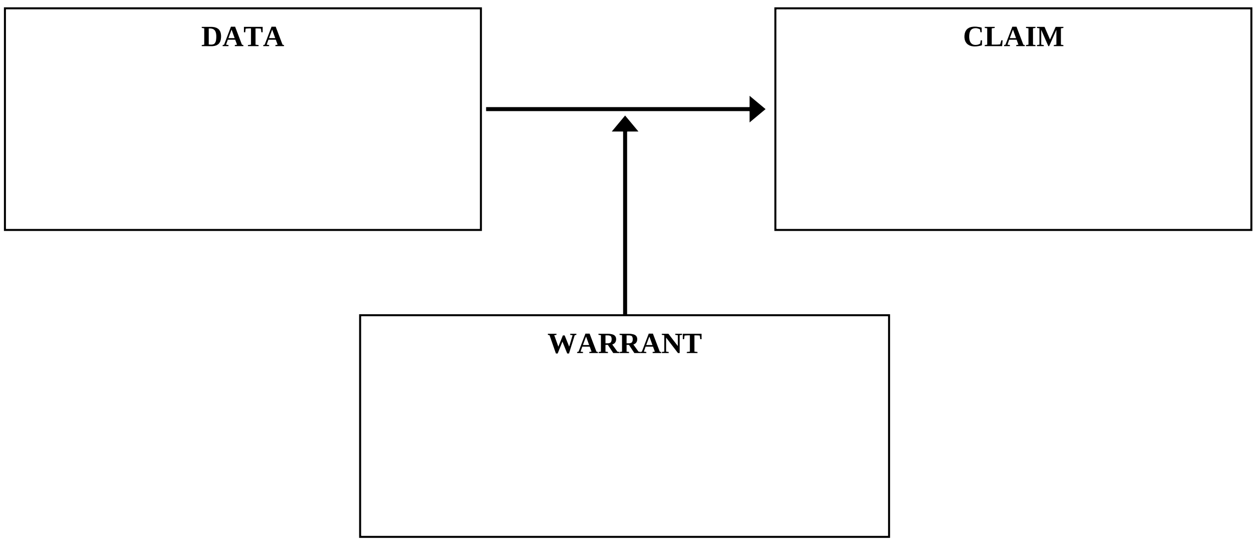
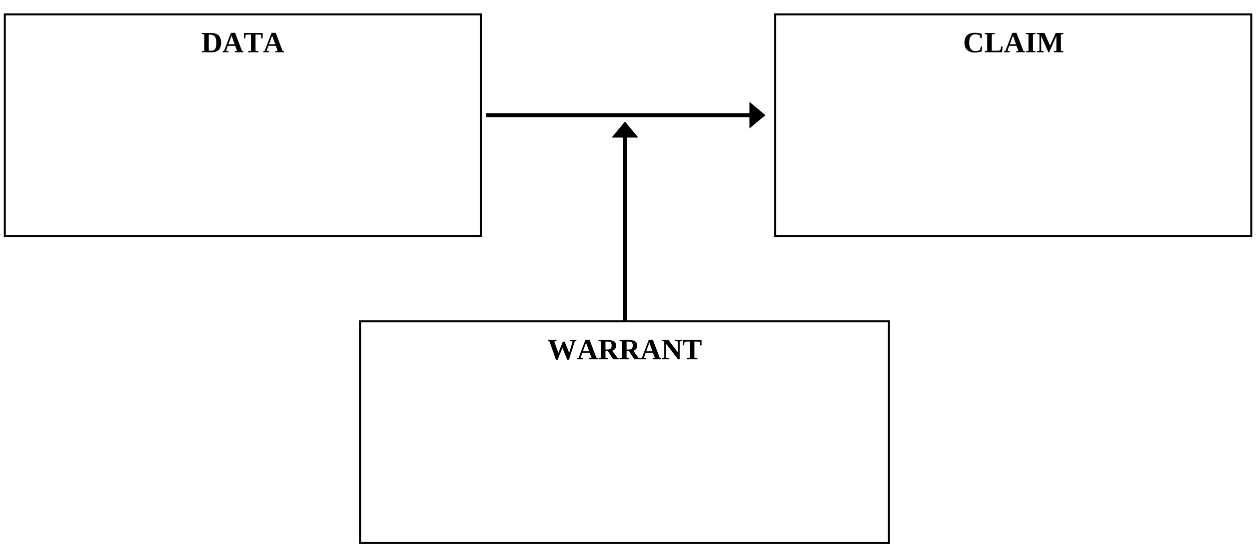
2. <u>Hypothesis Generation: What are possible causes of the patient's problem?</u>

(1) I think that she may have blood cell disorder. An abnormality in her platelets, which help blood clot, can cause bleeding and disorders involving white blood cells, such as the abnormal number or function of WBCs, can leave the body open to infection.



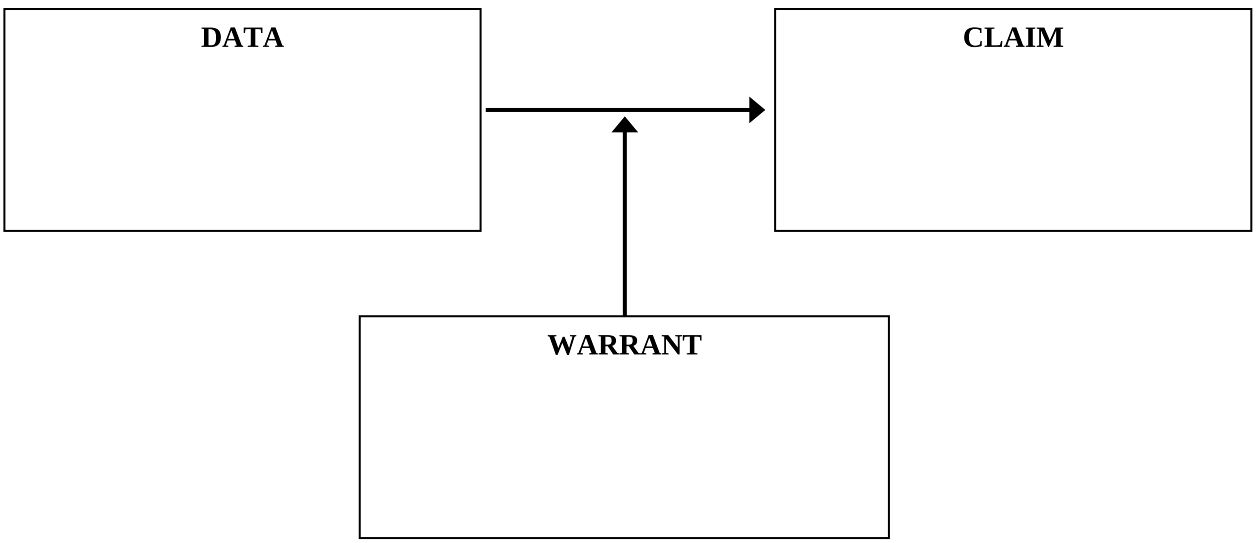
(2) She complains of oral ulcers and bruising.



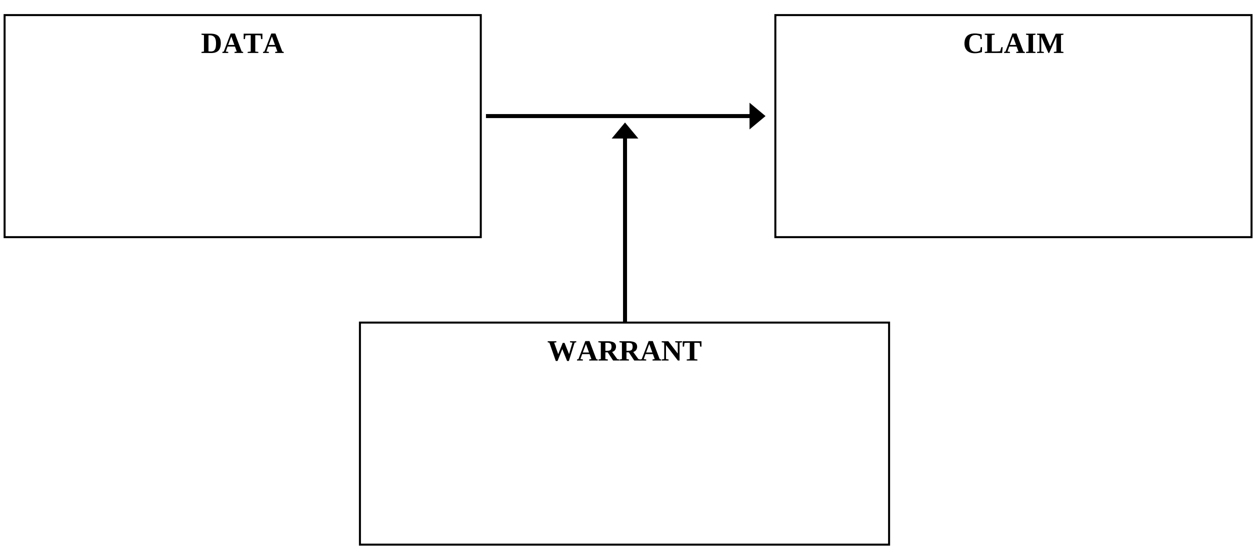
Ms. Hong, 48 years old, came into a hospital. She feels lethargic, sometimes has a fever, and has pain in her mouth. She said that she often has swollen gums, canker sores, and bruises on her arms and body. Swollen gums, oral ulcers, and small petechiae on her palate as well as buccal mucosa were found in the results of the physical examinations. She also had bruises on her arms and body.

3. **Inquiry Strategy: What inquiry strategies or actions would be necessary for hypothesis testing?**

(1) The complete blood count [CBC] would be necessary. The CBC measures the different cells in the blood, such as the red and white blood cells and the platelets. It may show abnormally high white blood cell counts. In addition, there may be an abnormality in the red blood cells or platelets.



(2) I think a bone marrow test would need to be performed.



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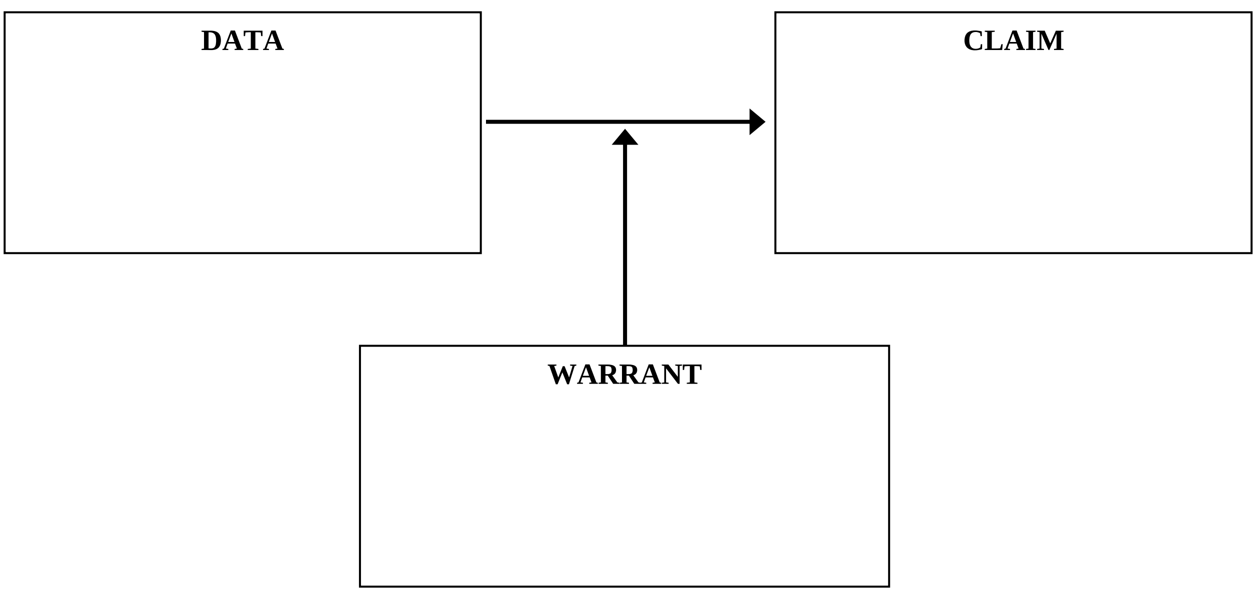
Blood Test	Result	Reference Intervals
Hb	8.0 mg/dL	13-18 mg/dL
MCV	94 fL	80-100 fL
MCH	31 pg	27-32 pg
MCHC	32 mg/dL	30-35 mg/dL
WBC	$2.5 * 10^9$/L	$4.0\text{-}11.0 * 10^9$/L
Differential: Neutrophils	6%	$2.0\text{-}7.5 * 10^9$/L
Eosinophils		$0.04\text{-}0.4 * 10^9$/L
Basophils		$< 0.1 * 10^9$/L
Lymphocytes	90%	$1.5\text{-}4.0 * 10^9$/L
Monocytes	4%	$0.2\text{-}0.8 * 10^9$/L
Platelet count	$11 * 10^9$/L	$150\text{-}400 * 10^9$/L

4. **<u>Data Analysis/Synthesis: What is your interpretations of the patient's data?</u>**

   Her Hb is 8.0 mg/dL and WBC is $2.5 * 10^9$/L.



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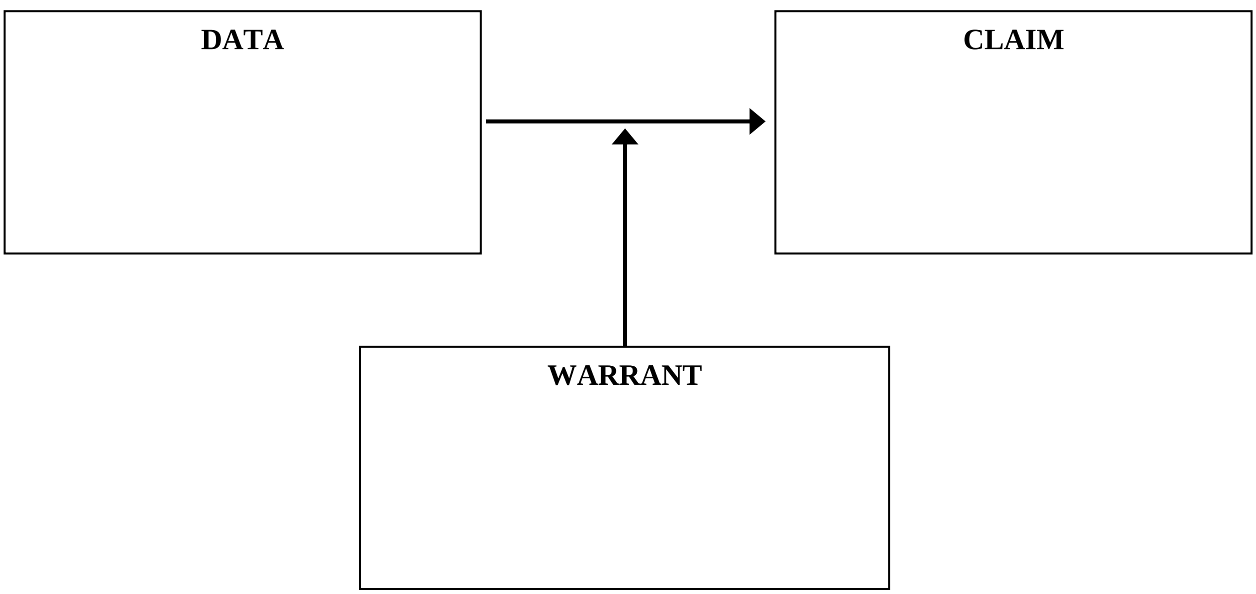
Monocytes	4%	0.2-0.8 *10^9/L
Platelet count	11 * 10^9/L	150-400 * 10^9/L

In addition, the results of the bone marrow aspiration and biopsy are fatty, hypocellular marrow with markedly reduced hematopoiesis.

5. **<u>Diagnostic Decision: What is the patient's most likely diagnosis?</u>**

   I think the most likely diagnosis is aplastic anemia.



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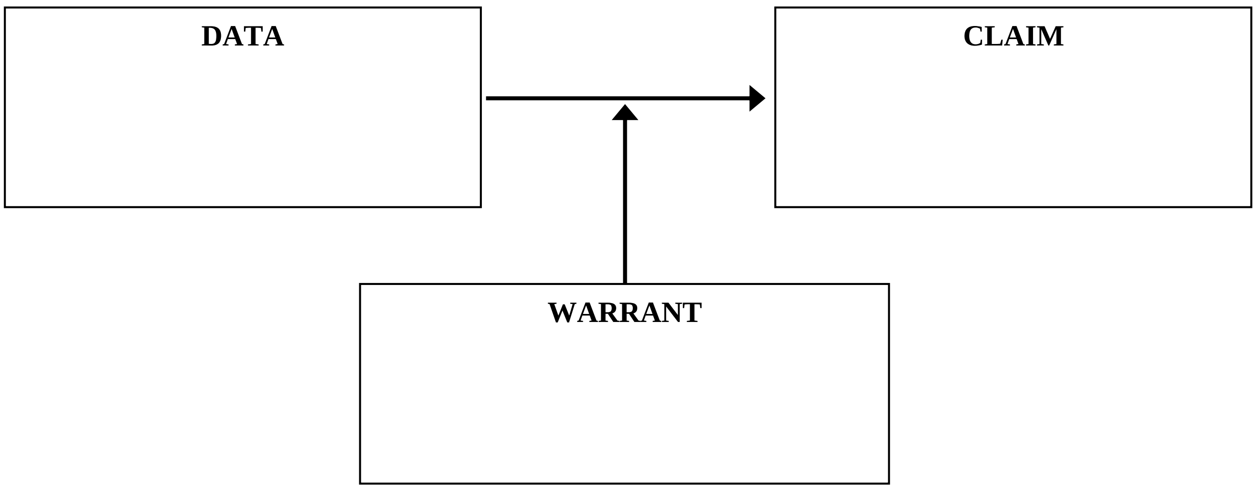
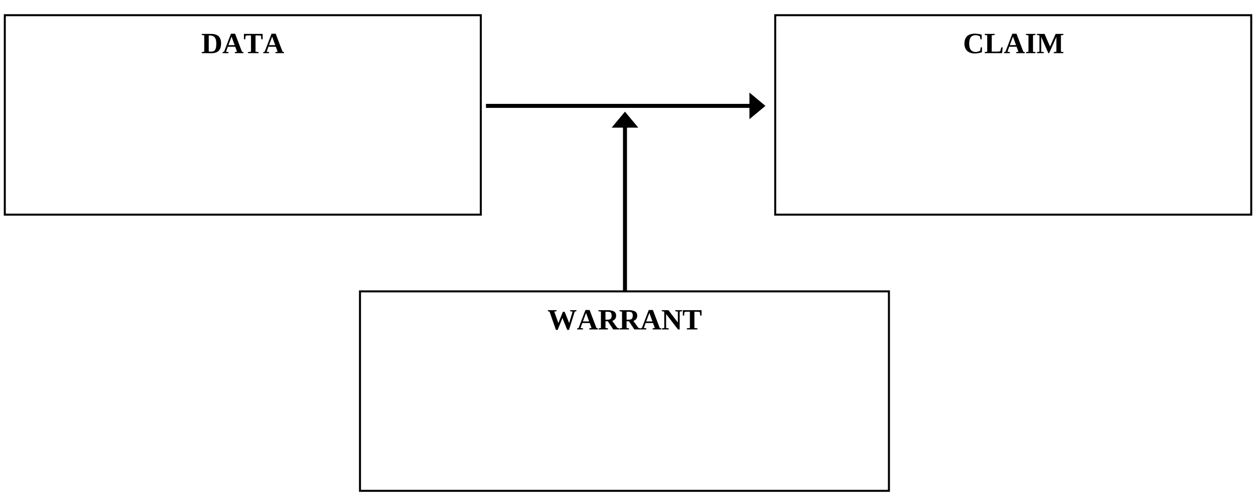
6. Therapeutic Decision: How should this patient be treated?

(1) Blood transfusions may be required for a patient with aplastic anemia.



(2) The patient has aplastic anemia. It may be necessary to provide immunosuppressive drugs, such as cyclosporin or anti-thymocyte globulin, if the patient can't undergo a bone marrow transplant or if she is waiting for a transplant. These drugs suppress the activity of immune cells that are damaging the bone marrow. This helps the bone marrow recover, lets stem cells grow back, and raises blood counts, which can relieve the patient's symptoms.



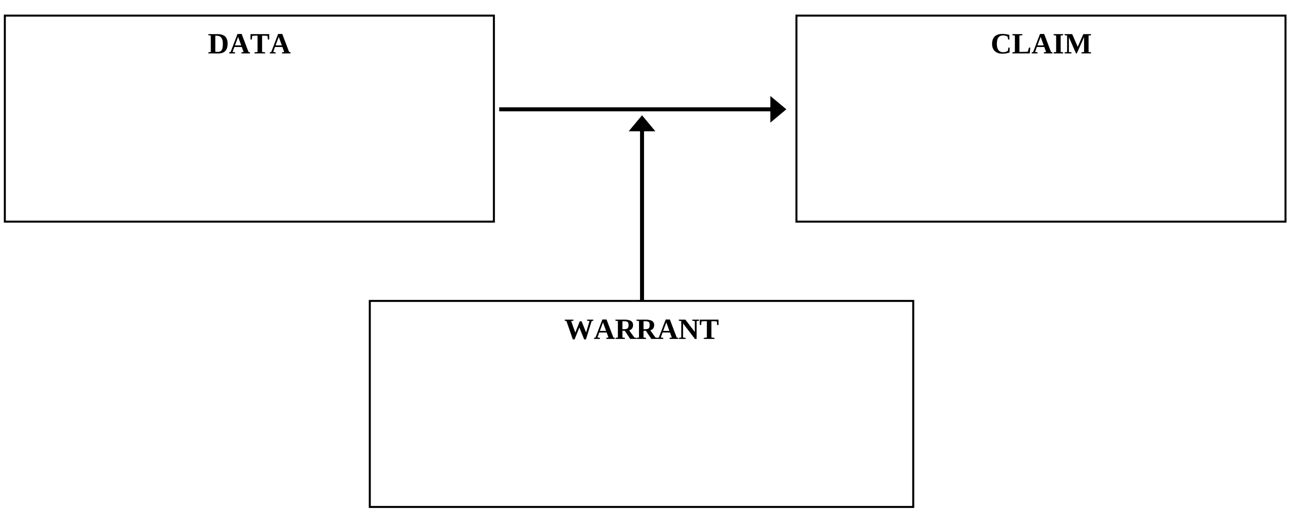
ACTIVITY II: ARGUMENTATION PRACTICE

Mr. Gil-dong Hong, a 34-year-old construction worker, came into the clinic with lethargy and yellow-colored skin. He told the doctor that his urine has darkened and his stools have turned gray for the last week. He drank one bottle of soju every day. His sclera has become yellow, and his abdomen has been bloated.

<u>Question 1:</u>

Please generate your argument(s) about hypotheses of the patient's problem.

Please complete your peer's argument(s) on an argument diagram form and evaluate his or her argument(s) <u>using a peer review checklist</u>.



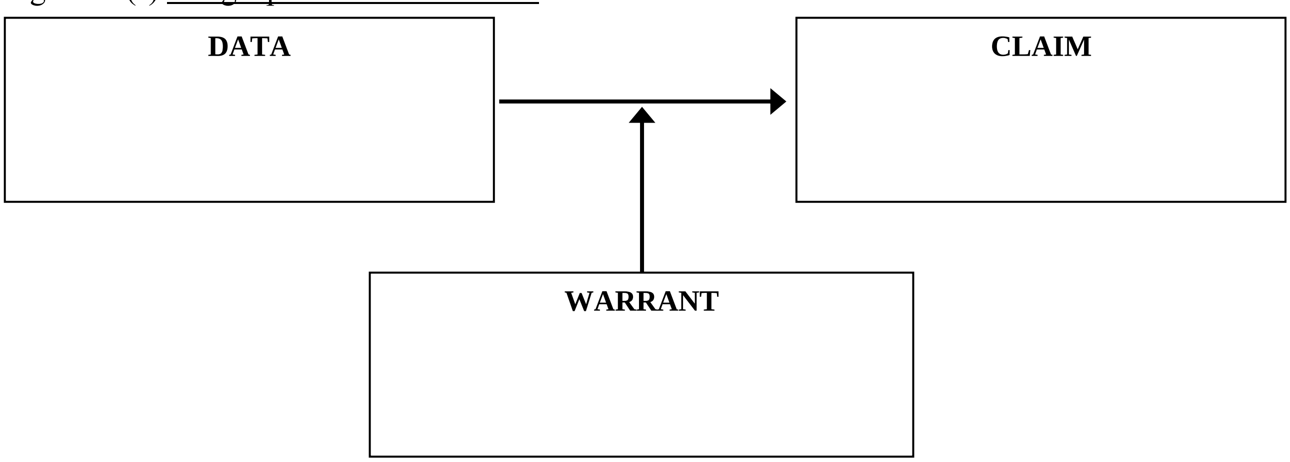
Mr. Gil-dong Hong, a 34-year-old construction worker, came into the clinic with lethargy and yellow-colored skin. He told the doctor that his urine has darkened and his stools have turned gray for the last week. He drank one bottle of soju every day. During his physical examination, it was noted that his sclera and skin are yellow and his abdomen is bloated, but there is not a shifting dullness over the abdomen.

Blood Test	Result	Reference Intervals
WBC	10,740/mm^3	4,000-1,0000
Hb	11.0 g/dL	14.0-18.0
MCV	106 fL	77-91
Platelet count	140,000/ mm^3	140,000-440,000
AST	124 IU/L	7-38
ALT	51 IU/L	4-43
ALP	660 IU/L	104-338
γGTP	168 IU/L	8-48
Albumin	2.5 g/dL	4.0-5.0
Prothrombin time	18.9 sec.	10.0-13.0
Bilirubin total	24.7 mg/dL	0.2-1.1
Direct bilirubin	18.2 mg/dL	0.0-0.6

Question 2:

Please generate your argument(s) about the data (blood test results) analysis.

Please complete your peer's argument(s) on an argument diagram form and evaluate his or her argument(s) using a peer review checklist.



The patient's case was adapted from a patient's case used for a modified essay question (MEQ) during the gastrointestinal system at Inje University College of Medicine.

PEER REVIEW CHECKLIST

Reviewer:

Question 1: Argument about Hypothesis Generation			
	Criteria	**YES**	**NO**
General	• Does the argument include a claim, data, and a warrant?		
Claim	• Is it clear and complete?		
	• Does it state a possible disease responsible for the patient’s problem?		
Data (Evidence)	• Is it clear and complete?		
	• Does it state the patient’s information or cues relevant to the claim?		
Warrant	• Is it clear and complete?		
	• Does it state an explanation of basic mechanism(s) relevant to the claim and data?		
Comments			

Question 2: Argument about Data Analysis			
	Criteria	**YES**	**NO**
General	• Does the argument include a claim, data, and a warrant?		
Claim	• Is it clear and complete?		
	• Does it state interpretation(s) on the patient’s data?		
Data (Evidence)	• Is it clear and complete?		
	• Does it state the patient’s data relevant to the claim?		
Warrant	• Is it clear and complete?		
	• Does it state an explanation of basic mechanism(s) relevant to the claim and data?		
Comments			

APPENDIX A.3

WORKSHOP FOR TUTORS

THE STRUCTURE OF ARGUMENTATION

- *Argumentation* refers to the process of constructing ideas and providing justifications for the ideas
  - Components of argumentation

    (1) Claim: An expression of the position that is advanced in an argument

    (2) Data (Evidence): Factual information to provide support for the claim

    (3) Warrant: Reasons that justify the connection between the data and the claim

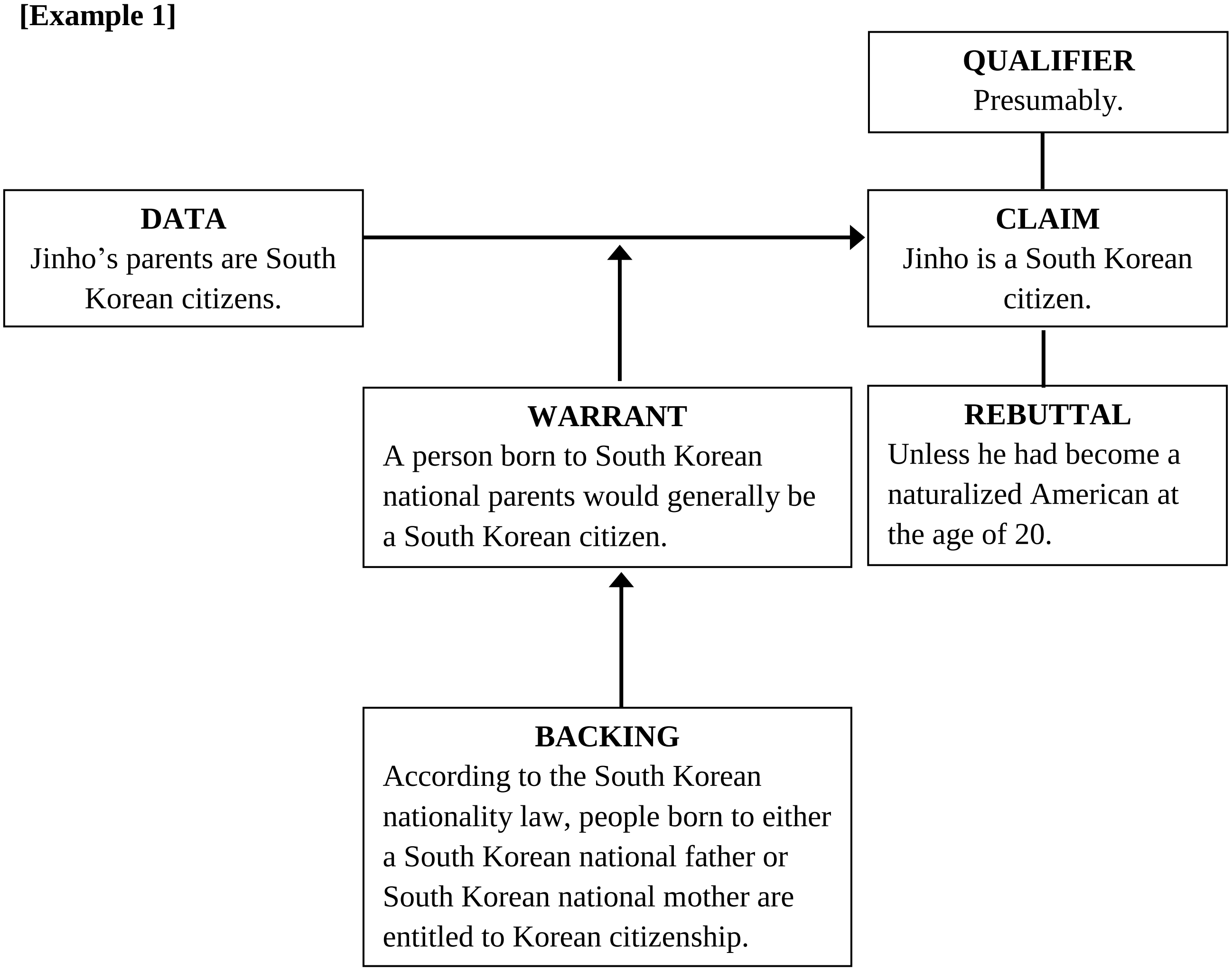
    (4) Backing: Statements to support the warrant

    (5) Rebuttal: Exceptions or limitations to the claim

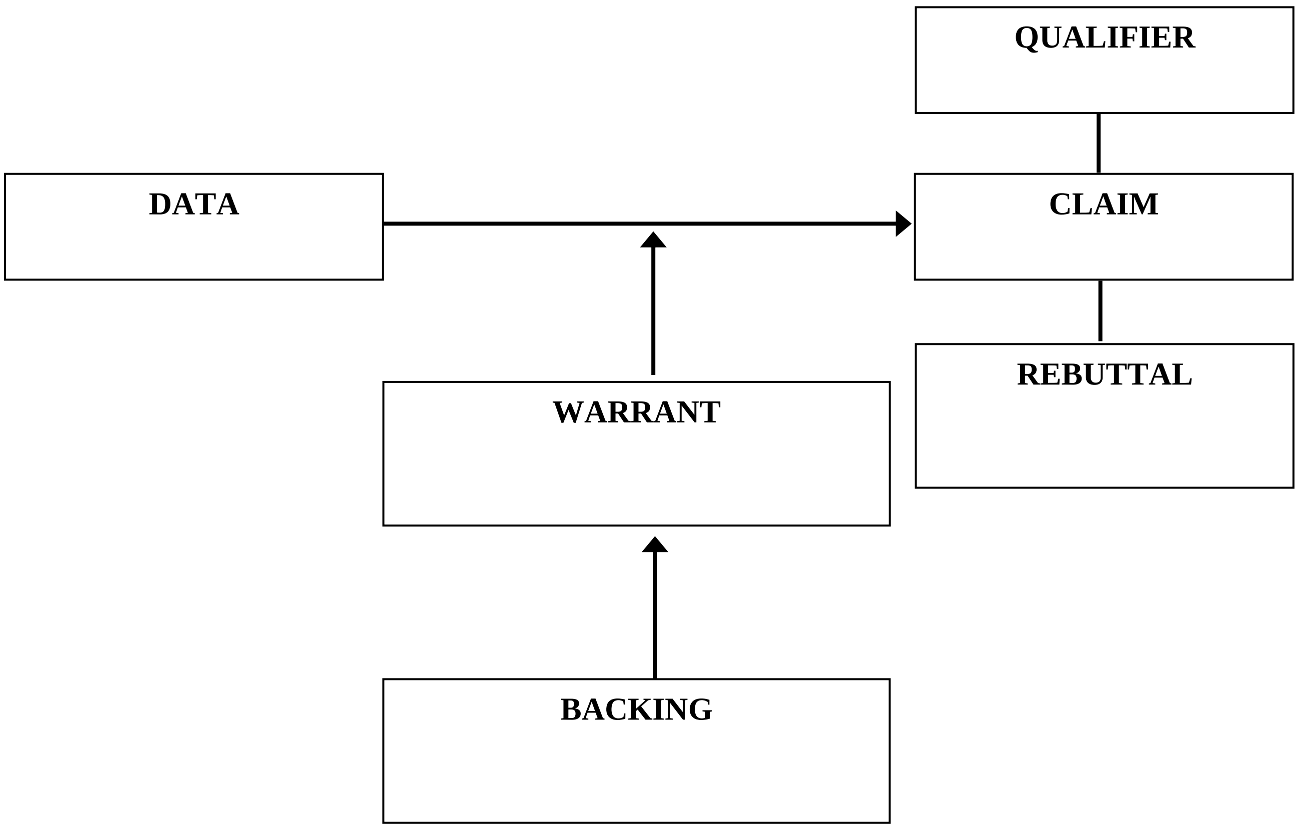
    (6) Qualifier: Words or phrases to express limited certainty of the claim (e.g., perhaps)

    **** The claim, data, and warrant are essential components of an argument!***

[Example 1]



[Example 2] Yuri's bedroom is probably on fire, because smoke is pouring out of Yuri's bedroom. Smoke is a primary sign of fire, since fires generally produce smoke. Unless the smoke is a product of a chemical reaction, it may not be enough to say that her bedroom is on fire.

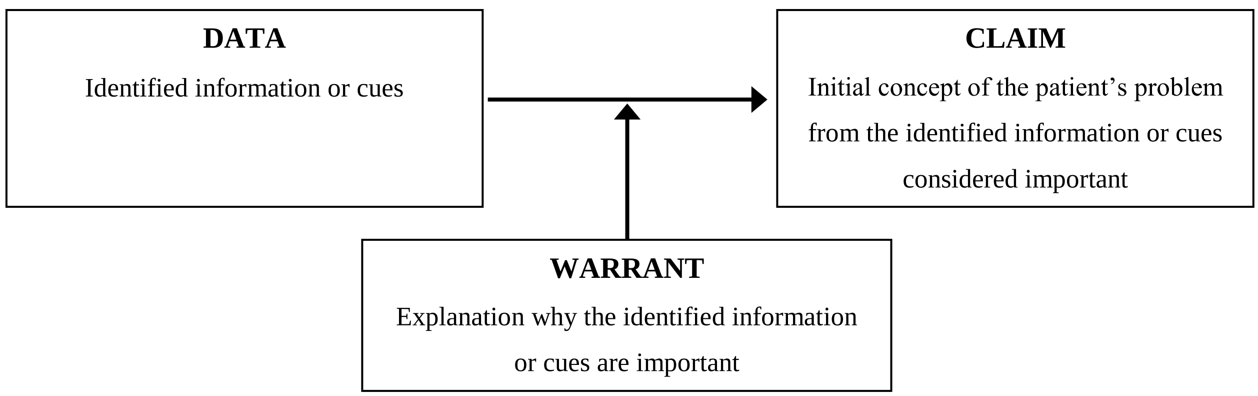


THE STRUCTURE OF ARGUMENTATION IN

THE HYPOTHETICO-DEDUCTIVE REASONING PROCESS

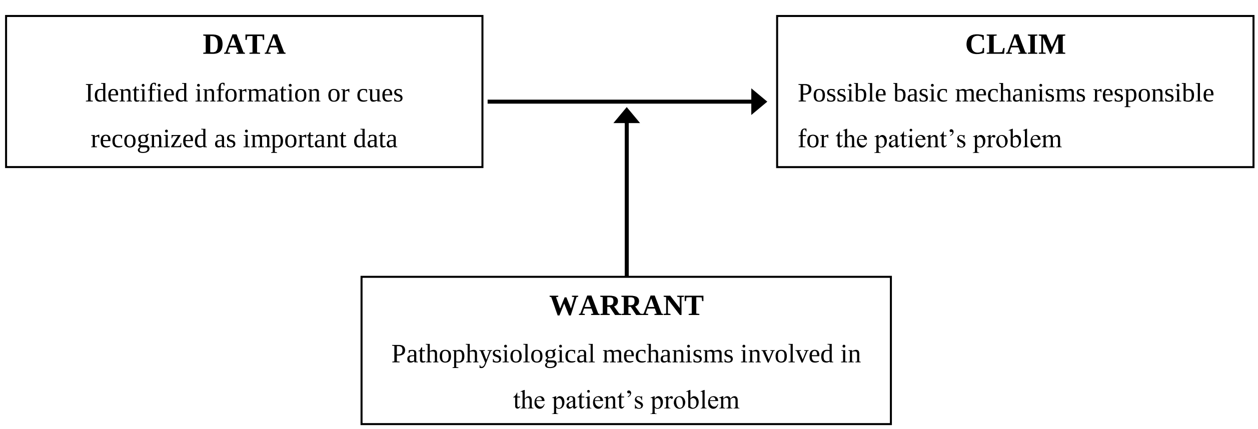
**** The essential components of an argument, <u>claim, data, and warrant,</u> should be included!***

<u>Phase 1: Problem Framing</u>



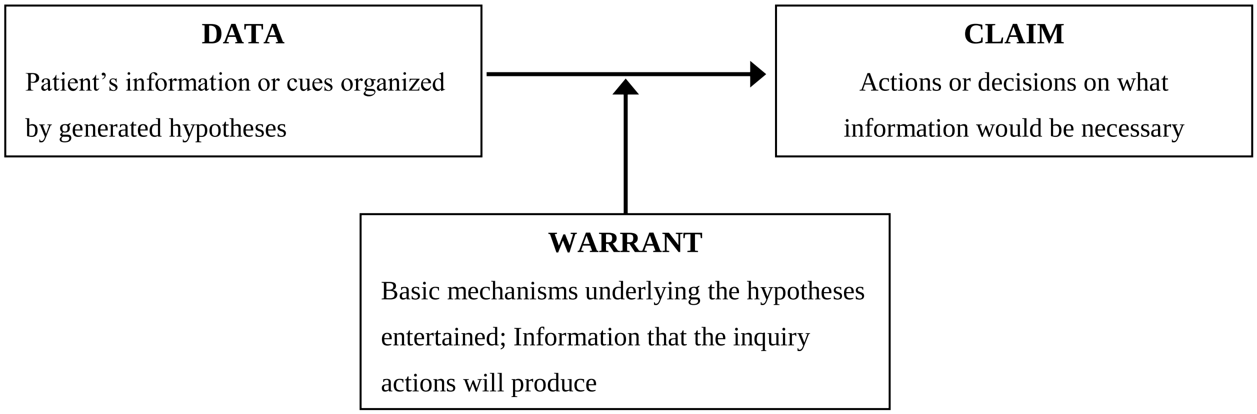
[Example] The patient is pale and vomiting fresh blood **<u>(Data)</u>**. She has a history of vomiting fresh blood mixed with food **<u>(Warrant)</u>**, so I think her chief complaint is hematemesis **<u>(Claim)</u>**.

<u>Phase 2: Hypothesis Generation</u>



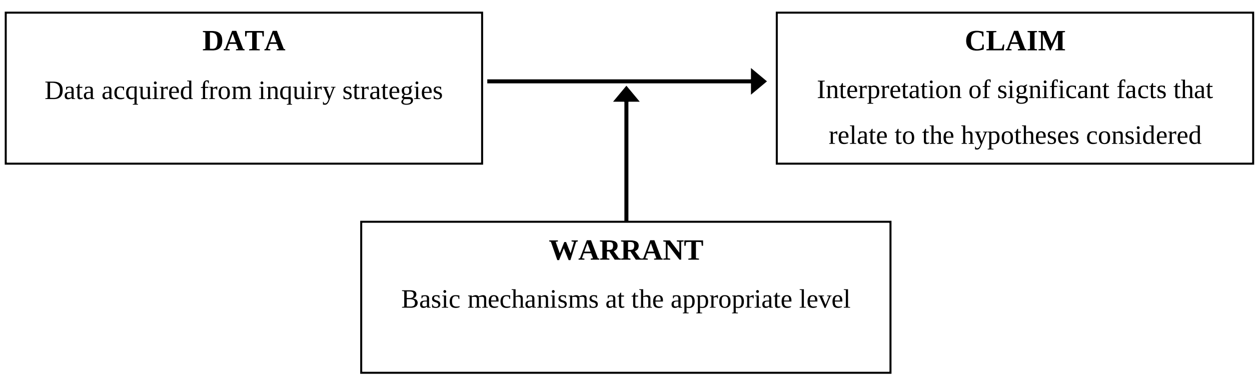
[Example] I think that the patient may have a decrease in the blood supply to her brain **<u>(Claim)</u>**, because her complaints are pallor and a loss of consciousness **<u>(Data)</u>**. A decrease in the blood supply to the brain can cause pallor and a lack of oxygen and nutrients supplied to the brain, which results in a loss of consciousness **<u>(Warrant)</u>**.

Phase 3: Inquiry Strategy



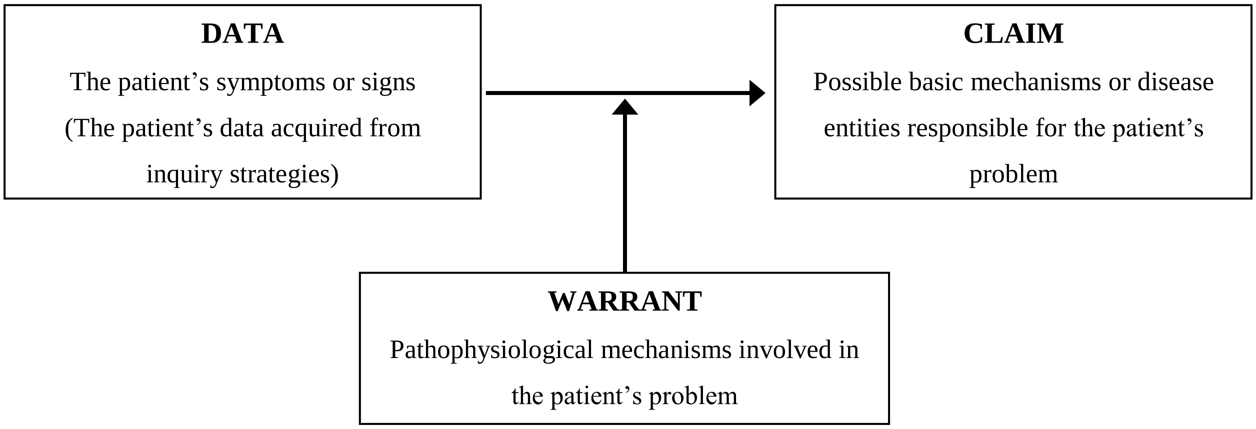
[Example] I think a CBC [complete blood count] would be necessary **(Claim)**, because the patient may have bleeding in her upper GI tract **(Data)**. The hematocrit is used to measure the percentage of the volume of whole blood that is made up of red blood cells, which helps to assess the extent of significant blood loss **(Warrant)**.

Phase 4: Data Analysis/Synthesis



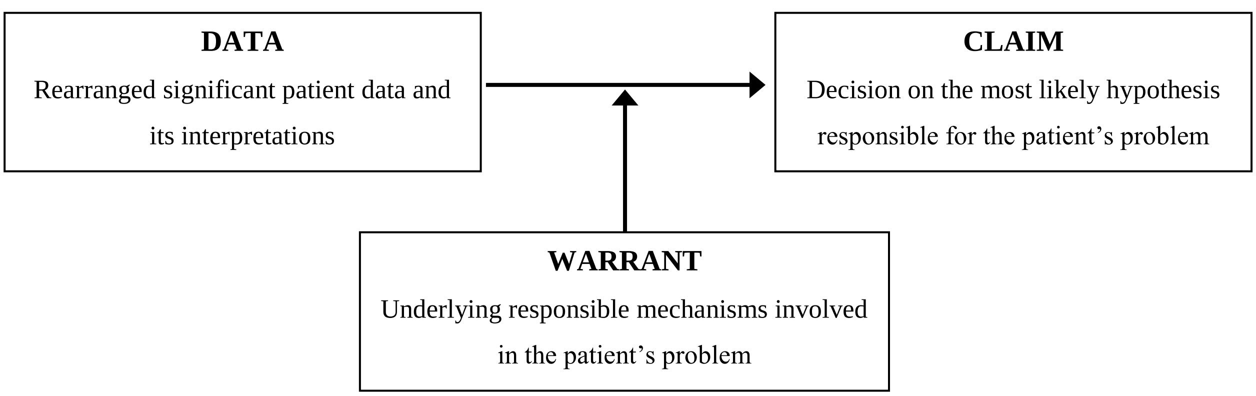
[Example] Like multi-organ failure, kidney failure is likely to occur **(____)** because of hematuria **(____)**. Since blood supply dysfunction and hypoxia were seen in the patient, they can result in kidney failure, which can cause blood in the urine **(____).**

Phase 5: Hypothesis Regeneration (* Replicable until arriving at Diagnostic Decision)



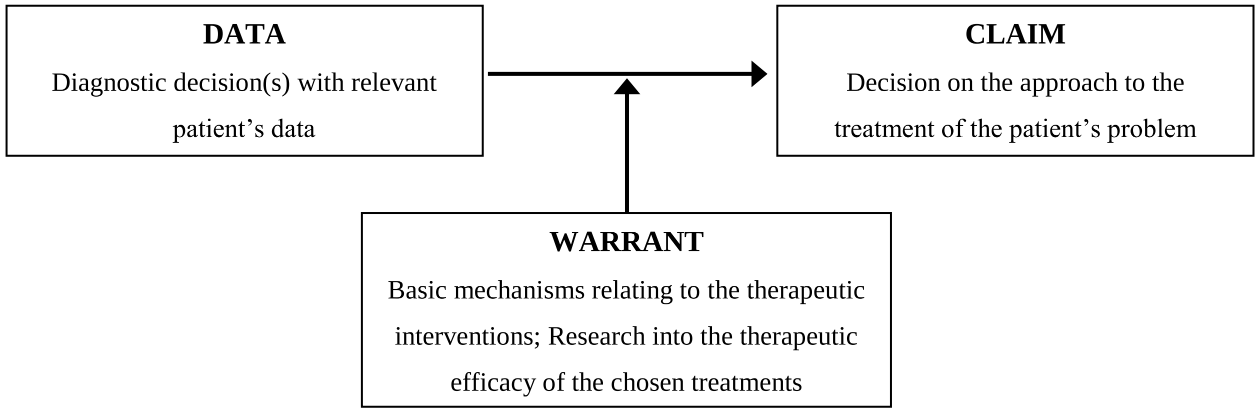
[Example] Lower gastrointestinal tract bleeding is the most likely among our hypotheses **(____)**. The patient has a history of a large amount of blood in her stool, is in a semi-coma, and has a blood pressure of 70/40mmHg **(____)**. Blood loss leads to reduced cardiac output, which decreases cerebral blood volume and oxygen supplies to the central nervous system [CNS], which disrupts the function of the CNS, resulting in a loss of consciousness **(____)**.

Phase 6: Diagnostic Decision



[Example] The patient's chief complaint is vomiting, and as results of the endoscopy, ulcerative lesions in the duodenum and gastric outlet obstructions were found **(____)**. Regions around the ulcers are swollen, which can cause gastric outlet obstruction, which in turn can result in vomiting **(____)**. Thus, I think the most likely diagnosis is a duodenal ulcer **(____).**

Phase 7: Therapeutic Decision



[Example] The patient's diagnosis is SAH [subarachnoid hemorrhage] **(____)**. It may be necessary to provide the patient with mannitol to reduce the ICP [intracranial pressure] **(____)**. An increase in the ICP is caused by bleeding, and mannitol cannot cross the blood-brain barrier, that will osmotically dehydrate the brain, which will cause water to move from the brain tissue into the blood vessels, which in turn will lower cerebrospinal fluid pressure resulting in decreased ICP **(____).**

ACTIVITY: THE STRUCTURE OF ARGUMENTATION IN THE HYPOTHETICO-DEDUCTIVE REASONING PROCESS

The following statements are students' arguments generated during each process of clinical reasoning about the following patient's case. Please evaluate each of the statements using an argument diagram form. If there is any missing component(s) of argumentation in the statements, please think about questions that you will ask the students as a tutor in order to facilitate them to construct a complete argument, including the three components of argumentation (a claim, data, and a warrant).

[Case] Ms. Hong, 48 years old, came into a hospital. She feels lethargic, sometimes has a fever, and has pain in her mouth. She said that she often had swollen gums, canker sores, and bruises on her arms and body.

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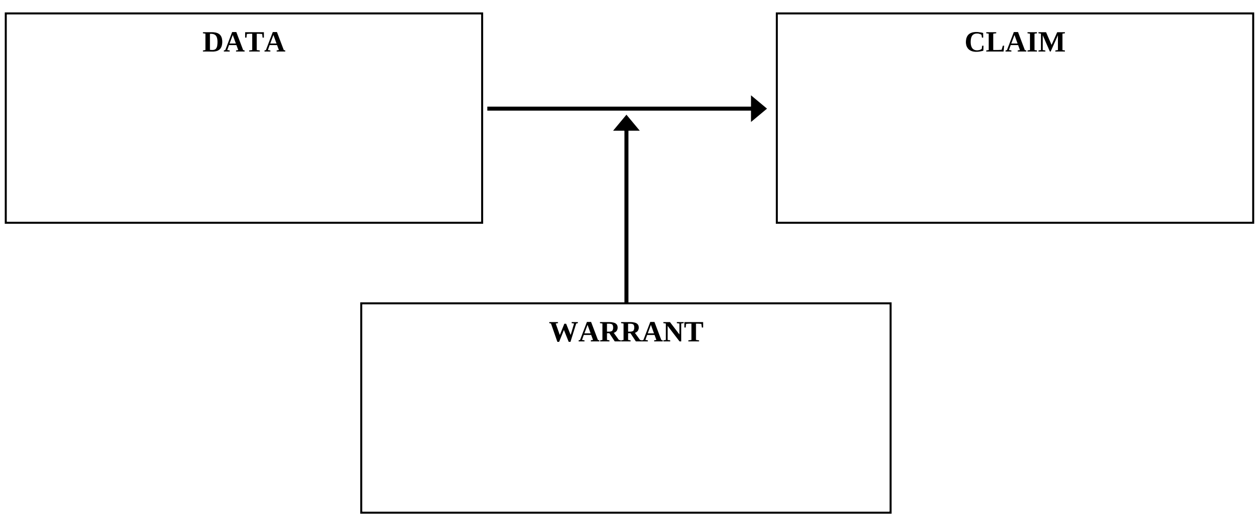

What is a missing component of argumentation in the argument?

What questions could you ask?

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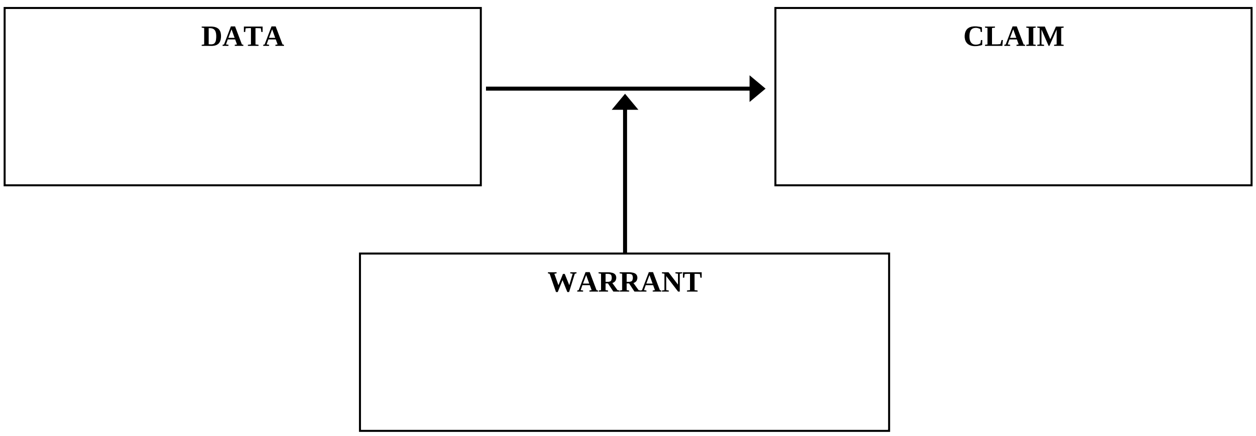

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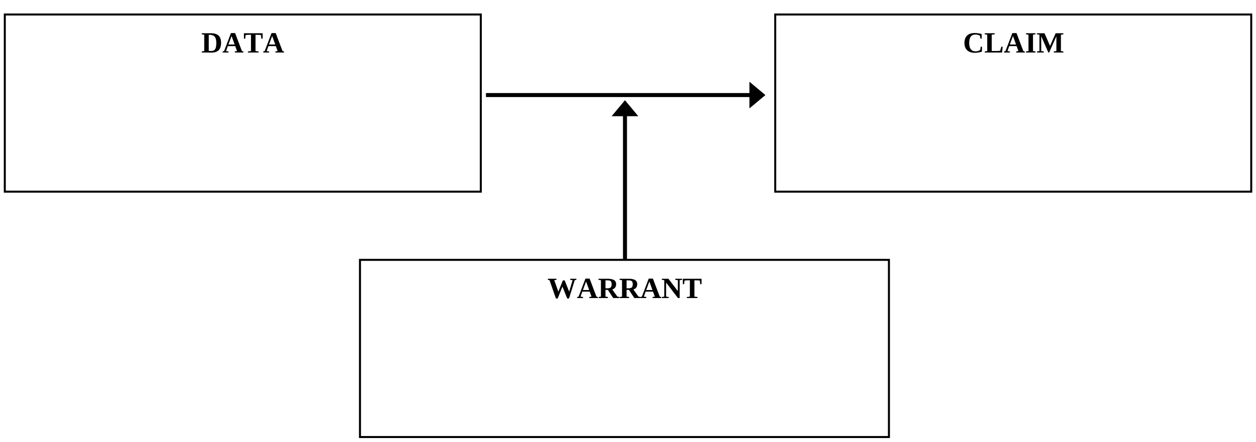

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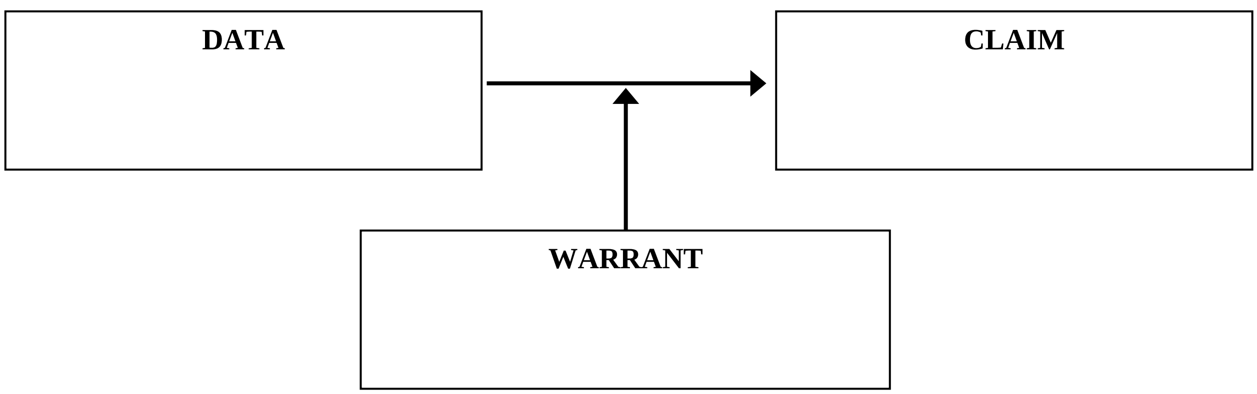

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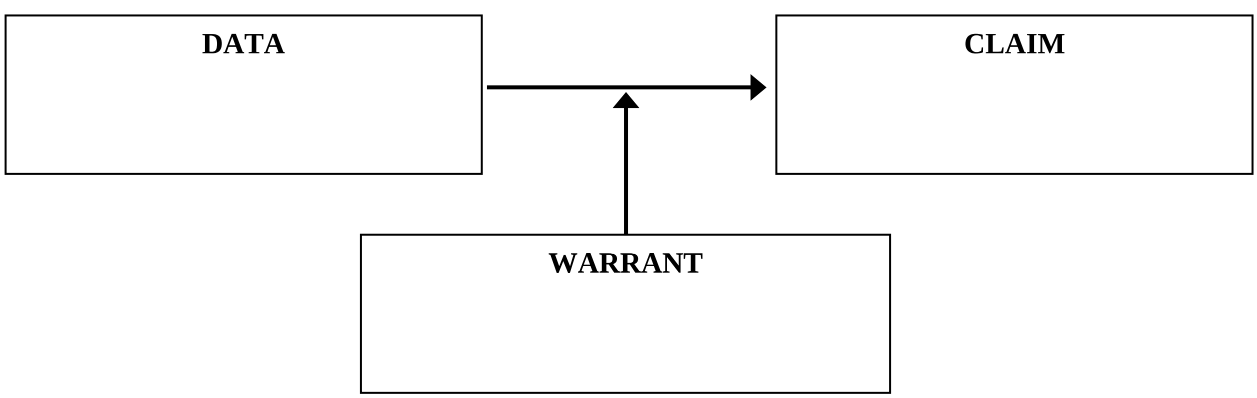

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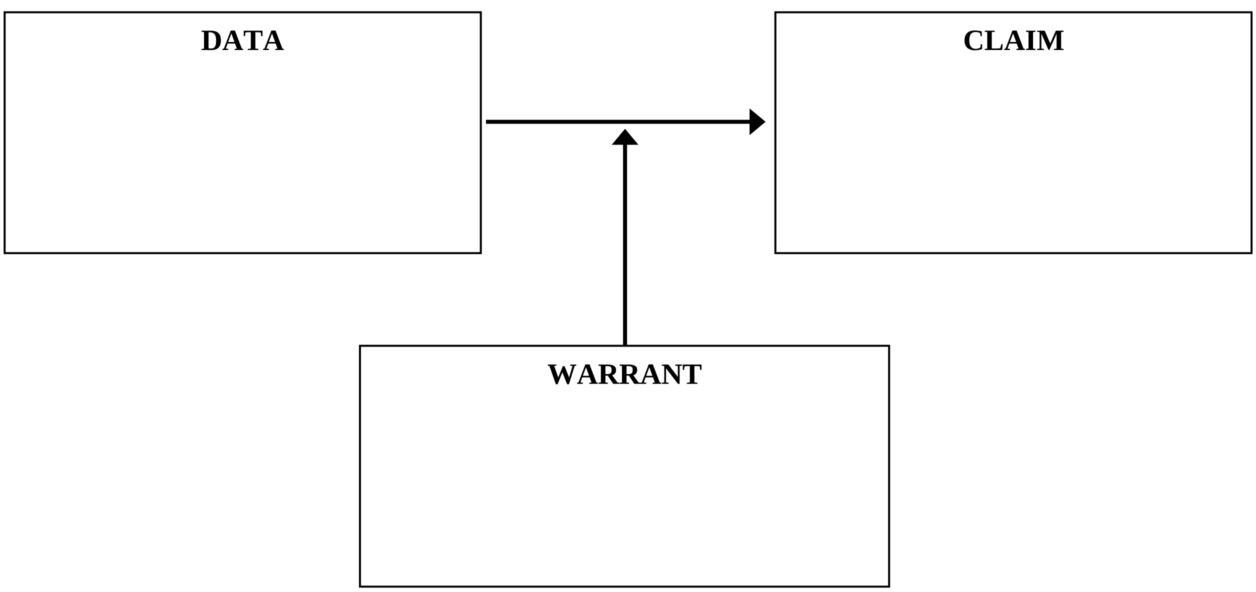


<u>What is a missing component of argumentation in the argument?</u>

<u>What questions could you ask?</u>

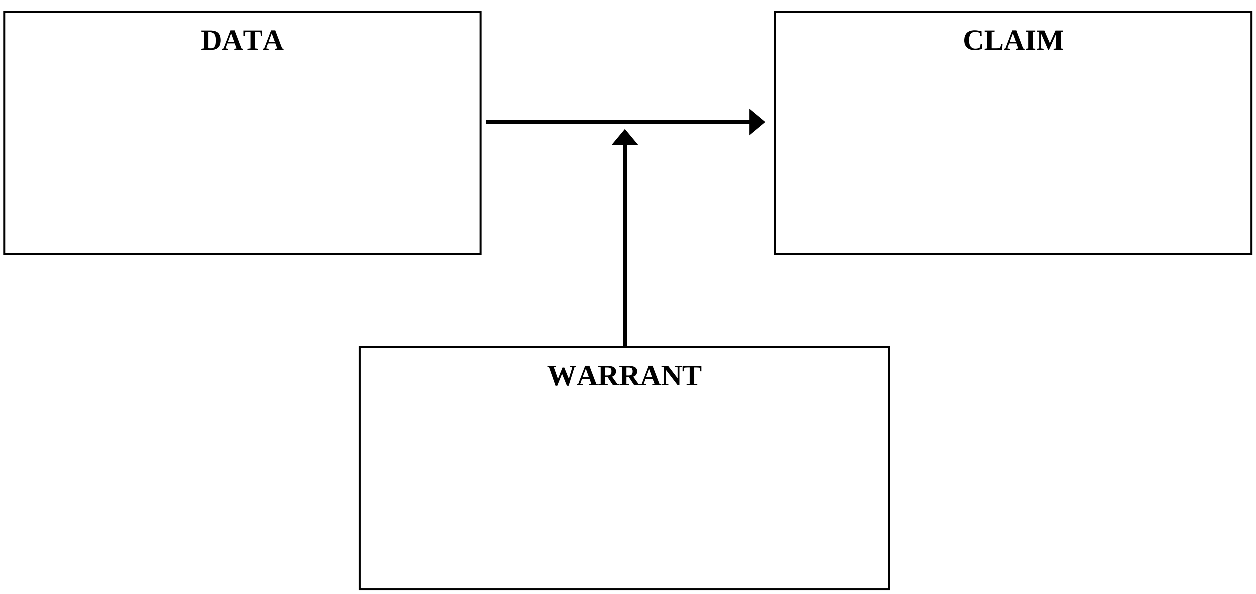
Ms. Hong, 48 years old, came into a hospital. She feels lethargic, sometimes has a fever, and has pain in her mouth. She said that she often has swollen gums, canker sores, and bruises on her arms and body. Swollen gums, oral ulcers, and small petechiae on her palate as well as buccal mucosa were found in the results of the physical examinations. She also had bruises on her arms and body. The results of the blood tests are as follows:

Blood Test	Result	Reference Intervals
Hb	8.0 mg/dL	13-18 mg/dL
MCV	94 fL	80-100 fL
MCH	31 pg	27-32 pg
MCHC	32 mg/dL	30-35 mg/dL
WBC	$2.5 * 10^9$/L	$4.0\text{-}11.0 * 10^9$/L
Differential: Neutrophils	6%	$2.0\text{-}7.5 * 10^9$/L
Eosinophils		$0.04\text{-}0.4 * 10^9$/L
Basophils		$< 0.1 * 10^9$/L
Lymphocytes	90%	$1.5\text{-}4.0 * 10^9$/L
Monocytes	4%	$0.2\text{-}0.8 * 10^9$/L
Platelet count	$11 * 10^9$/L	$150\text{-}400 * 10^9$/L

In addition, the results of the bone marrow aspiration and biopsy are fatty, hypocellular marrow with markedly reduced hematopoiesis.

5. **<u>Diagnostic Decision: What is the patient's most likely diagnosis?</u>**

I think the most likely diagnosis is aplastic anemia.



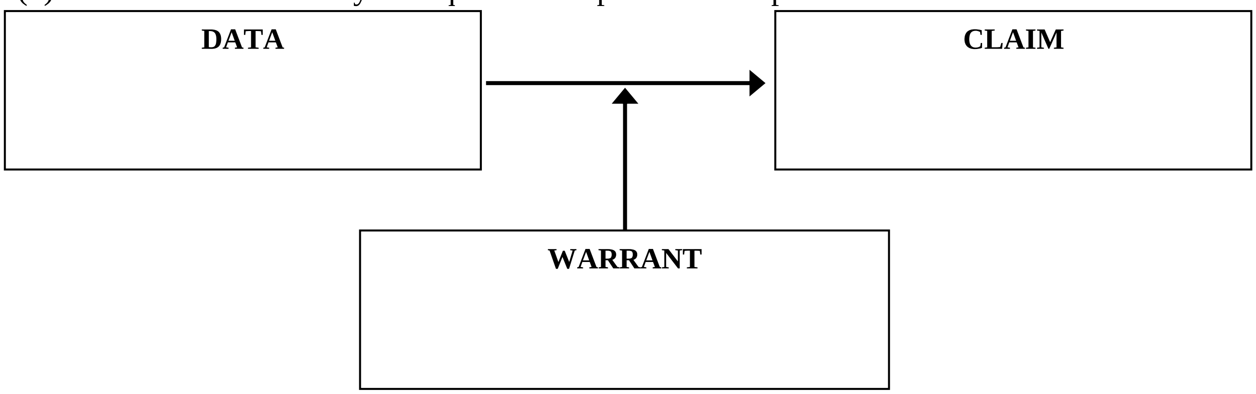
What is a missing component of argumentation in the argument?

What questions could you ask?

Ms. Hong, 48 years old, came into a hospital. She feels lethargic, sometimes has a fever, and has pain in her mouth. She said that she often has swollen gums, canker sores, and bruises on her arms and body. Swollen gums, oral ulcers, and small petechiae on her palate as well as buccal mucosa were found in the results of the physical examinations. She also had bruises on her arms and body. As a result of the blood test and the bone marrow aspiration and biopsy, she is diagnosed with aplastic anemia.

6. **<u>Therapeutic Decision: How should this patient be treated?</u>**

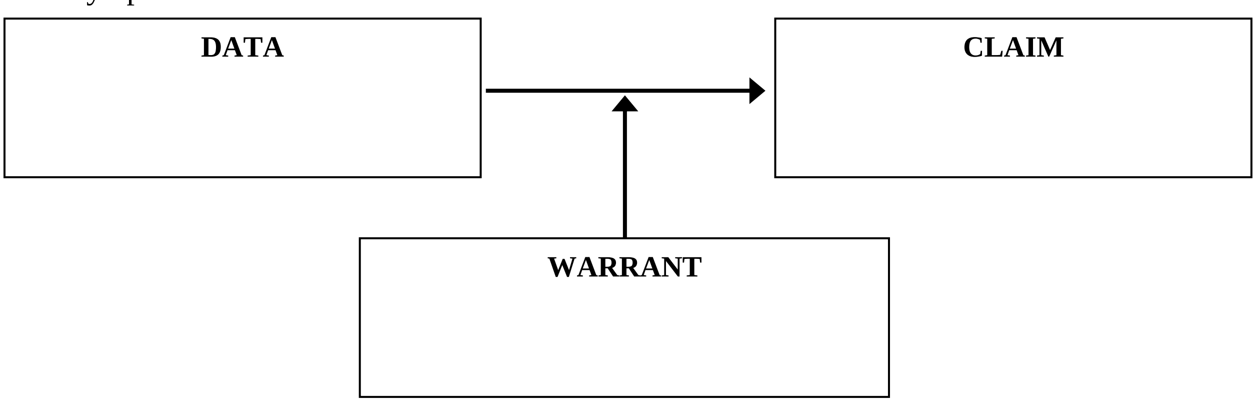
(1) Blood transfusions may be required for a patient with aplastic anemia.



<u>What is a missing component of argumentation in the argument?</u>

<u>What questions could you ask?</u>

(2) The patient has aplastic anemia. It may be necessary to provide immunosuppressive drugs, such as cyclosporin or anti-thymocyte globulin, if the patient can't undergo a bone marrow transplant or if she is waiting for a transplant. These drugs suppress the activity of immune cells that are damaging the bone marrow. This helps the bone marrow recover, lets stem cells grow back, and raises blood counts, which can relieve the patient's symptoms.



<u>What is a missing component of argumentation in the argument?</u>

<u>What questions could you ask?</u>

APPENDIX B.1

QUESTION PROMPTS FOR STUDENTS

1. <u>Questions for Argumentation</u>

Please use the following questions as a guide as you construct arguments including the three essential components (a claim, data, and a warrant).

	Argument Component	**Questions**
General Argumentation	Claim	• What is my idea?
	Data	• What data (evidence) can support my claim?
	Warrant	• What is my explanation for how the data (evidence) can support the claim?

2. Questions for Argumentation during the Hypothetico-Deductive Reasoning Process

Please use the following questions as a guide as you construct arguments including the three essential components (a claim, data, and a warrant) during each phase of hypothetico-deductive reasoning in PBL.

1) 1st PBL Session

HDR Process	Argument Component	Questions
Problem Framing	Claim	• What is the patient's problem?
	Data	• What information or cues seem important here? • What do I notice?
	Warrant	• Why do I find the information or cues important?
Hypothesis Generation	Claim	• What are possible basic mechanisms responsible for the patient's problem?
	Data	• What is significant patient information (cues) for supporting my hypothesis?
	Warrant	• What pathophysiological mechanisms might be involved in the patient's problem?
Inquiry Strategy	Claim	• What actions (interview questions or physical examination items) would need to be performed? • What information would be necessary for hypothesis testing?
	Data	• Which hypotheses are related to the actions/information considered necessary? • Which patient information (cues) is related to the actions considered necessary?
	Warrant	• Why are the questions (or physical exams) necessary for the patient?
Data Analysis/Synthesis	Claim	• What is the significance of the result from inquiry strategies (interview or physical examination)? • What does the result do for the hypotheses considered?
	Data	• What data can support the interpretation?
	Warrant	• What are basic mechanisms responsible for that finding?
Hypothesis Regeneration	Claim	• What are other possible basic mechanisms or disease entities responsible for the patient's problem?
	Data	• What are the patient's significant data for supporting my hypothesis?
	Warrant	• What pathophysiological mechanisms might be involved in the patient's problem? • How do the disease entities lead to the patient's problem?

2) 2nd PBL Session

HDR Process	Argument Component	Questions
Hypothesis Regeneration	Claim	• What are other possible basic mechanisms or disease entities responsible for the patient's problem?
	Data	• What are the patient's significant data for supporting my hypothesis?
	Warrant	• What pathophysiological mechanisms might be involved in the patient's problem? • How do the disease entities lead to the patient's problem?
Therapeutic Decision **(*If acute managements necessary)**	Claim	• What acute management(s) should be provided for the patient?
	Data	• What is the patient's symptom or sign for my decision on the acute management?
	Warrant	• How can the acute management improve the patient's condition in terms of basic mechanisms? • How is the acute management helpful for the patient's symptoms or signs?
Inquiry Strategy	Claim	• What actions (laboratory or diagnostic tests) would need to be performed? • What information would be necessary for hypothesis testing?
	Data	• Which hypotheses are related to the actions/information considered necessary? • Which patient information (cues) is related to the actions considered necessary?
	Warrant	• Why are the tests necessary for the patient? • What information can the test produce? • What do I know about the test?
Data Analysis/Synthesis	Claim	• What is the significance of the result from inquiry strategies (tests)? • What does the result do for the hypotheses considered?
	Data	• What data can support the interpretation?
	Warrant	• What are basic mechanisms responsible for that finding?
Diagnostic Decision	Claim	• What is the most likely hypothesis?
	Data	• What are the significant data to support the diagnosis?
	Warrant	• How is the primary diagnosis supported by the symptoms/findings? • What are the basic mechanisms related to the diagnosis?
Therapeutic Decision (Principles of management)	Claim	• What treatments/ managements should be provided for the patient?
	Data	• What is the patient's diagnosis or clinical data for my decision on the approach to the treatment?
	Warrant	• How can the treatment correct the patient's problem in terms of basic mechanisms? • How is the treatment helpful for the disease?

3) 3rd PBL Session

HDR Process	Argument Component	Questions
Therapeutic Decision (Short-/Long-term management)	Claim	• What treatments/ managements should be provided for the patient? o What are primary managements for the patient? o What are long-term managements or approaches to secondary prevention for the patient? o Besides medical or surgical treatments, what are other managements (e.g., patient education)?
	Data	• What is the patient's diagnosis or clinical data for my decision on the approach to the treatment?
	Warrant	• How can the treatment correct the patient's problem in terms of basic mechanisms? • How is the treatment helpful for the disease?

APPENDIX B.2

QUESTION PROMPTS FOR TUTORS

1. Questions for Students' Argumentation

Please use the following questions as you facilitate students' argumentation including the three essential components (a claim, data, and a warrant).

	Argument Component	**Description**	**Questions**
General Argumentation	Claim	Asks for making a clear and complete assertion	• What is your idea?
	Data	Asks for providing supporting data with claims clearly	• What data (evidence) can support your claim?
	Warrant	Asks for an explanation of the connection between the data and the claim	• Can you explain that the data (evidence) can support the claim?

2. Questions for Students' Argumentation during the Hypothetico-Deductive Reasoning Process

Please use the following questions as you facilitate students' argumentation including the three essential components (a claim, data, and a warrant) during each phase of hypothetico-deductive reasoning (HDR).

1) 1st PBL Session

HDR Process	Argument Component	Description	Questions
Problem Framing	Claim	Asks for formulation of a patient's problem	• What do you think is the patient's problem?
	Data	Asks for providing identified information or cues to support the patient's problem formulation	• What information or cues seem important here? • What do you notice?
	Warrant	Asks for an explanation why the identified information or cues are important	• Why do you think the information or cues are important?
Hypothesis Generation	Claim	Asks about possible basic mechanisms responsible for the patient's problem	• What do you think are possible basic mechanisms responsible for the patient's problem?
	Data	Asks for providing identified information or cues considered important	• What is significant patient information (cues) for supporting your hypothesis?
	Warrant	Asks for an explanation of pathophysiological mechanisms that seem possible in the patient's problem	• What pathophysiological mechanisms might be involved in the patient's problem?
Inquiry Strategy	Claim	Asks about what actions/ information would be necessary and important for hypothesis testing	• What actions (interview questions, or physical examination items) would need to be performed? • What information do you need?
	Data	Asks for relating actions/information considered necessary to the hypotheses entertained or the patient's information (cues)	• Which hypotheses are related to the actions/information considered necessary? • Which patient information (cues) are related to the actions considered necessary?
	Warrant	Asks for an explanation of why the actions/information would be necessary	• Why do you think that the questions (or physical exams) are necessary for the patient?

HDR Process	Argument Component	Description	Questions
Data Analysis/ Synthesis	Claim	Asks for interpretations on results from inquiry strategies (interview or physical examination)	• What is the significance of the result? • What does the result do for the hypotheses considered?
	Data	Asks about evidence to support the interpretations of results from inquiry strategies	• What data can support the interpretation?
	Warrant	Asks for an explanation of how the results help to define the mechanisms responsible	• What are basic mechanisms responsible for that finding?
Hypothesis Regeneration	Claim	Asks about other possible basic mechanisms or disease entities responsible for the patient's problem	• What are other possible basic mechanisms or disease entities responsible for the patient's problem?
	Data	Asks for providing identified information or cues considered important	• What are the patient's significant data for supporting my hypothesis?
	Warrant	Asks for an explanation of pathophysiological mechanisms that seem possible in the patient's problem	• What pathophysiological mechanisms might be involved in the patient's problem? • How do the disease entities lead to the patient's problem?

2) 2nd PBL Session

HDR Process	Argument Component	Description	Questions
Hypothesis Regeneration	Claim	Asks about other possible basic mechanisms or disease entities responsible for the patient's problem	• What are other possible basic mechanisms or disease entities responsible for the patient's problem?
	Data	Asks for providing identified information or cues considered important	• What are the patient's significant data for supporting my hypothesis?
	Warrant	Asks for an explanation of pathophysiological mechanisms that seem possible in the patient's problem	• What pathophysiological mechanisms might be involved in the patient's problem? • How do the disease entities lead to the patient's problem?
Therapeutic Decision **(*If acute managements necessary)**	Claim	Asks about necessary acute managements for the patient	• What acute management(s) should be provided for the patient?
	Data	Asks for providing data (evidence) for the acute management decision	• What is the patient's symptom or sign for my decision on the acute management?
	Warrant	Asks for an explanation of why the certain acute management should be performed in terms of basic mechanisms	• How can the acute management improve the patient's condition in terms of basic mechanisms? • How is the acute management helpful for the patient's symptoms or signs?
Inquiry Strategy	Claim	Asks about what actions/ information would be necessary and important for hypothesis testing	• What actions (laboratory or diagnostic tests) would need to be performed? • What information do you need?
	Data	Asks for relating actions/information considered necessary to the hypotheses entertained or the patient's information (cues)	• Which hypotheses are related to the actions/information considered necessary? • Which patient information (cues) are related to the actions considered necessary?
	Warrant	Asks for an explanation of why the actions/information would be necessary	• Why do you think that the tests are necessary for the patient?

HDR Process	Argument Component	Description	Questions
Data Analysis/ Synthesis	Claim	Asks for interpretations on results from inquiry strategies (tests)	• What is the significance of the result? • What does the result do for the hypotheses considered?
	Data	Asks about evidence to support the interpretations of results from inquiry strategies	• What data can support the interpretation?
	Warrant	Asks for an explanation of how the results help to define the mechanisms responsible	• What are basic mechanisms responsible for that finding?
Diagnostic Decision	Claim	Asks about the diagnosis of the patient's problem	• What do you think is the most likely hypothesis?
	Data	Asks about the patient's data obtained to support the diagnostic decision	• What are the significant data to support your diagnosis?
	Warrant	Asks for an explanation of underlying responsible mechanisms involved in the patient's problem	• How is your primary diagnosis supported by the symptoms/findings? • Can you explain how you came to the diagnosis in terms of basic mechanisms?
Therapeutic Decision (Principles of management)	Claim	Asks about necessary treatments/managements for the patient	• What treatments/managements should you provide for the patient?
	Data	Asks for providing data (evidence) for the treatment decision	• What is the patient's diagnosis or clinical data for my decision on the approach to the treatment?
	Warrant	Asks for an explanation of why the certain treatment approaches should be performed in terms of basic mechanisms	• Can you explain how the treatment can correct the patient's problem in terms of basic mechanisms? • How is the treatment helpful for the disease?

3) 3rd PBL Session

HDR Process	Argument Component	Description	Questions
Therapeutic Decision (Short-/Long-term management)	Claim	Asks about necessary treatments/managements for the patient	• What treatments/managements should you provide for the patient? o What are primary managements for the patient? o What are long-term managements or approaches to secondary prevention for the patient? o Besides medical or surgical treatments, what are other managements (e.g., patient education)?
	Data	Asks for providing data (evidence) for the treatment decision	• What is the patient's diagnosis or clinical data for my decision on the approach to the treatment?
	Warrant	Asks for an explanation of why the certain treatment approaches should be performed in terms of basic mechanisms	• Can you explain how the treatment can correct the patient's problem in terms of basic mechanisms? • How is the treatment helpful for the disease?

APPENDIX C.1

INTERVIEW QUESTIONS FOR STUDENTS

1. What's your experience with argumentation during the two PBL courses?
2. When did you refer to materials for the workshop or question prompts during argumentation in the PBL courses? How did you use them?
3. How was the workshop on the structure of argumentation helpful to your argumentation activity during the clinical reasoning process in the PBL courses? Or, why wasn't it helpful?
4. How were the question prompts helpful to your argumentation activity during the clinical reasoning process? Or, why weren't it helpful?
5. How was the tutor's questioning helpful to you or your group for engaging in argumentation during the clinical reasoning process in the PBL courses? Or, why wasn't it helpful?
6. What do you think about argumentation during the clinical reasoning process in PBL?
7. What suggestions do you have for effective argumentation during the clinical reasoning process in PBL?

   - What additional guidance would help you have better argumentation?

APPENDIX C.2

INTERVIEW QUESTIONS FOR TUTORS

1. What's your experience facilitating students' group discussions during PBL sessions before receiving any strategies for promoting students' argumentation?
2. What's your experience facilitating students' group discussions during PBL sessions after receiving the strategies for promoting students' argumentation?
3. How did the workshop on the structure of argumentation help you facilitate students' argumentation during the PBL course? Or, why didn't it?
4. How did the question prompts help you facilitate students' argumentation during students' clinical reasoning processes in the PBL course? Or, why didn't they?
5. When facilitating students' argumentation during students' clinical reasoning processes in the PBL course, what challenges did you experience? Why?
6. What suggestions do you have for students' effective argumentation during the clinical reasoning process in PBL?

   - What additional tutors' guidance would help you support students' argumentation?