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Understanding of Middle School Students' Cognitive Collaboration in Group Modeling on Blood Circulation

중학생의 혈액 순환에 대한 소집단 모델링 과정에서 나타나는 인지적 협력 이해

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Understanding of Middle School Students' Cognitive Collaboration in Group Modeling on Blood Circulation

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Abstract

Scientists generate, evaluate, and modify models to explain phenomena and communicate with others. Modeling is also significant in science education because it allows students to generate, evaluate, and modify the explanation of phenomena in terms of epistemic practice. In this study, the group modeling-based inquiry lessons about blood circulation were designed to develop middle school students' modeling abilities through learning by cognitive collaboration. With these, this study aimed to understand the epistemic process through cognitive collaboration in group modeling-based learning. The study is consisted of following three parts.

The study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling' aimed to explore the patterns of model development and the factors that led to differences in reasoning among several groups developing one-way circulation models. Fourteen students in gifted science education center participated in this study. Participants engaged in group modeling activities about one-way blood flow in the heart. After analyzing discourse, the patterns of model development were identified as the *unchanged*, the *added*, and the *elaborated.* The patterns of model development were decided by interaction within group members. The high-level reasoning process necessary for strong scientific argument was found in the *elaborated* pattern. The analogy model activity and the cognitive conflict within groups were the factors that influenced high-level reasoning.

Based on the finding from of the study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative

Modeling' that shaped the critical role of evaluation for model development, the study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' aimed to explore epistemological features and model qualities depending on the model evaluation levels and to identify reasoning processes revealed in a high-level of model evaluation. 34 students in K middle school participated in three modeling-based lessons. The third lesson in which students drew diagrams of blood circulation as group model was chosen for analyzing the epistemological features and model qualities. The model evaluation levels were defined as Levels 1 to 4 based on the evaluation criteria; the higher levels reflected a greater depth of critical thought and metacognitive monitoring concerning the changeable nature of models and the explanatory nature of the model. At Level 4, students evaluated the explanatory nature of the model in terms of the processes and the mechanisms of the phenomena depicted. This evaluation was based on the epistemological belief of knowing that the model constructed within a group should be evaluated for further development and alteration.

In the highest level of model evaluation, reasoning processes through cognitive collaboration were well-expressed by statements concerning monitoring one's own and/or others' understanding. Based on this finding of the study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels', the study of 'Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling' aimed to identify the differences of expression of statements of deep learning approach (SD: Statements of the deep learning approach) according to the features of group modeling activities and to

explore cognitive collaboration during group modeling processes focusing on students' SD. Four students among participants in the study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' were selected for case study. They engaged in three modeling-based lessons about blood circulation. The dominant SD categories found in each lesson varied because of the different properties relevant to the modeling. Individual SD influenced collaborative modeling through the deep reasoning process. Cognitive collaboration involved cognitive scaffolding and critical monitoring: cognitive scaffolding contributed to the generation and elaboration of the model, whereas critical monitoring contributed to the evaluation and modification of the model.

These findings could contribute to understand how cognitive collaboration occurs during group modeling and have significant implications on how to design and implement group modeling lessons where students experience authentic epistemic practice in science classroom.

Keywords : cognitive collaboration, group modeling, blood circulation, model evaluation, practical epistemology, deep learning approach

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TABLE OF CONTENTS

List of Tables ······ viii

List of Figures ······ x

CHAPTER

Ⅰ. **INTRODUCTION** ······ 1

1. Significance of the Study ······ 1
2. Research Questions ······ 8
3. Research Overview ······ 10
4. Definitions of Terms ······ 13

Ⅱ. **THEORETICAL BACKGROUNDS** ······ **17**

1. Models and Modeling in Science Education ······ 17
   1.1. Models in Science Education ······ 17
   1.2. Modeling in Science Education ······ 25
   1.3. Collaborative Modeling ······ 27
   1.4. The Roles of Models and Modeling ······ 32
2. Models and Modeling of Blood Circulation ······ 35
3. Cognitive Reasoning in Modeling ······ 40
   3.1. Practical Epistemology Revealed in Model Evaluation ······ 40
   3.2. Argumentation in Modeling ······ 45
4. The Approaches to Learning Science in Collaborative Modeling ······ 48

Ⅲ. Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling ································ 54
1. Introduction ································ 54
2. Methods ································ 58
2.1. Participants ································ 58
2.2. Context ································ 59
3.3. Data Collection and Analysis ································ 61
3. Results and Discussions ································ 67
3.1. The Patterns of Group Model Development ····· 67
3.1.1. The unchanged patterns ································ 70
3.1.2. The added patterns ································ 71
3.1.2. The elaborated patterns ································ 74
3.2. Factors Influencing Reasoning Process in Group Modeling ································ 79
3.2.1. The differences of reasoning process according to the task features of modeling activities ······· 82
3.2.2. The reasoning processes influenced by cognitive conflict among group members ································ 86
4. Conclusions and Implications ································ 91

Ⅳ. Epistemological Features and Model Qualities Depending on the Model Evaluation Levels ······ 95
1. Introduction ······ 95
2. Methods ······ 98
2.1. Participants ······ 98
2.2. Context ······ 100
3.3. Data Collection and Analysis ······ 104
3. Results and Discussions ······ 114
3.1. Epistemological Features and Model Qualities Depending on the Levels of Model Evaluation ······ 115
3.1.1. The phase without model evaluation ······ 115
3.1.2. The phase of model evaluation using authoritative sources ······ 118
3.1.3. The phase of model evaluation using superficial criteria ······ 123
3.2. The Highest-Level Model Evaluation Process ·· 126
3.2.1. Checking self-understanding: Raising questions ······ 128
3.2.2. Monitoring others' understanding: Emergence after expression of an incorrect concepts ····· 133
4. Conclusions and Implications ······ 139

Ⅴ. Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group Modeling ·· 145
1. Introduction ·· 145
2. Methods ·· 149
2.1. Participants ·· 149
2.2. Task Characteristics of the Implemented Lessons 152
3.3. Data Collection and Analysis ······················ 157
3. Results and Discussions ································ 162
3.1. Patterns of Statements of the Deep Learning Approach Expression in Each Lesson ··························162
3.2. Cognitive Collaboration and Model Development Influenced by Statements of the Deep Learning Approach ··· 168
3.2.1. Cognitive scaffolding ························ 168
3.2.2. Critical monitoring ··························· 180
4. Conclusions and Implications ························· 185

Ⅵ. CONCLUSIONS AND IMPLICATIONS ············ 191
1. Conclusions ·· 191
2. Implications ··· 194

References ·· **198**
Appendix ·· **216**
국문초록 ·· **224**

List of Tables

Table II-1. Classification of the ontological status of models ······· 21
Table II-2. Modes of representation ··································· 22
Table II-3. Student leadership styles and associated goals ········· 30
Table II-4. Five epistemic features of scientific knowledge in model-based inquiry ······································ 34
Table II-5. Evaluation criteria according to a learning progression for understanding models as changeable entities ······· 44
Table II-6. Differences between deep and surface learning approach in scientific practice ·· 51
Table III-1. Description of boys and girls who participated in each group ·· 59
Table III-2. Patterns of group model development related to the interaction characteristics ································· 68
Table III-3. Differences of reasoning process in group modeling ·· 82
Table III-4. Differences between modeling phase 1 and 2·········· 85
Table IV-1. Levels of model evaluation and epistemological features ··· 113
Table IV-1. Coding scheme for model evaluation criteria··········· 114
Table V-1. Features of focal group students·························· 151
Table V-2. Characteristics of the implemented lessons ·············· 156
Table V-3. Framework for classification of the statements of the deep learning approach ··· 160
Table V-4. Group 6's discourse analysis on Episode 1 from Lesson 1 ··· 161
Table V-5. Frequencies of statements of the deep learning approach in each lesson ··· 163
Table V-6. Modeling relevant properties in each lesson ············ 167
Table V-7. Episode 1 in Lesson 3 (Systemic circulation: Heart-hand

muscle circuit) ·· 171
Table V-8. Episode 2 in Lesson 3 (Systemic circulation: Heart-brain circuit) ·· 172
Table V-9. Episode 4 in Lesson 3 (Pulmonary circulation) ········· 174
Table V-10. Episode 2 in Lesson 1 (One-way water flow in the siphon pump) ·· 178
Table V-11. Episode 4 in Lesson 3 (Systemic circulation: Heart-leg muscle circuit) ·· 183

List of Figures

Figure I-1. Research overview ·· 12
Figure II-2. Ontological status of models in this study··············· 20
Figure II-2. Theoretical framework of models in learning·········· 24
Figure II-3. GEM cycle ··· 26
Figure II-4. Learning pathway in model-based learning ············ 31
Figure II-5. The four interrelated conversation supporting model-based inquiry·· 45
Figure III-1. Process of the instruction································ 60
Figure III-2. Framework for model development – Modeling phase 1 of Group A ·· 63
Figure III-3. Target model of the modeling phase 1 ·················· 64
Figure III-4. Target model of the modeling phase 2·················· 65
Figure III-5. Framework for reasoning process of modeling ········ 66
Figure III-6. Discourse of the *unchanged* pattern – Modeling phase 2 of Group B ·· 71
Figure III-7. Discourse of the *added* pattern – Modeling phase 1 of Group C ··· 73
Figure III-8. Discourse of the *elaborated* pattern – Modeling phase 2 of Group A ·· 76
Figure III-9. Discourse of the *elaborated* pattern – Modeling phase 1 of Group D ·· 78
Figure III-10. Reasoning process in modeling phase 1 of Group A ··· 88
Figure III-11. Reasoning process in modeling phase 1 of Group B ··· 90
Figure IV-1. The implemented lessons of blood circulation ········ 102
Figure IV-2. Framework for the process of model development ··· 107
Figure IV-3. Target model represented in drawing of the blood

circulation ······························· 109
Figure IV-4. Target model represented in discourse ················ 110
Figure IV-5. Discourse during Group 8's model development of
pulmonary circulation ······························· 117
Figure IV-6. Group 8's discursive model of pulmonary circulation
······························· 118
Figure IV-7. Discourse during Group 4's model development of
systemic circulation ······························· 121
Figure IV-8. Group 4's diagram model of systemic circulation ···· 122
Figure IV-9. Discourse during Group 6's model development of
systemic circulation ······························· 125
Figure IV-10. Group 6's diagram model of blood circulation······· 126
Figure IV-11. Discourse during Group 1's model development of
systemic circulation ······························· 129
Figure IV-12. Group 1's diagram model of blood circulation and
discursive model of systemic circulation············ 132
Figure IV-13. Discourse during Group 6's model development of
pulmonary circulation and gas exchange············ 135
Figure IV-14. Group 6's diagram model of blood circulation and
discursive model of exchange of gases ·············· 138

Ⅰ. INTRODUCTION

1. Significance of the Study

Modeling is one of the key functions of scientists' activities (Nersessian, 2008); scientists generate, evaluate, and modify models to explain phenomena and communicate with others. Models can act as tools for scientists to understand the natural world, as they simplify and represent natural phenomena or experience and provide potential solutions for research questions (NRC, 2000). In other words, the construction of models, which can be defined as *modeling practice*, can serve the role of explaination as a kind of cognitive strategy in science (Odenbaugh, 2005). Through the use of modeling practice as one of the main methods of inquiry for scientific inquiries and the thinking process, students can be encouraged to participate in the process of learning science through modeling–based activities (Krajcik & Merritt, 2012).

In fact, modeling is considered to be a practice that enables students to experience scientists' work in the science classroom, and has recently been applied to the reformation of science education. As modeling reflects the generation, evaluation, and communication processes of scientific knowledge, it can be viewed as an epistemic practice through which students can experience social interaction using language (Duschl *et al.*, 2007). In this regard, Next Generation Science Standards (NGSS) in the U.S.

introduced a major practice that helps students develop and use models to learn core ideas (Achieve, Inc., 2013). To elaborate on earlier definitions, modeling is the process of explaining the relationships between systems or elements of a system based on empirical and conceptual evidence (Böttcher & Meisert, 2011; Mendonça & Justi, 2013; Passmore & Svoboda, 2012; Svoboda & Passmore, 2013). Hence, when students engage in modeling in science lessons, they not only describe empirical experiences such as experiments and observations; they also reason, explain, and communicate phenomena or systems using empirical experience as evidence. In other words, students can experience the epistemic process that science education aims to produce.

Students, however, have been provided scientists' models as simple illustrations; additionally, they also receive little time for exploring the evidence of models or constructing explanatory models of phenomena (Lehrer & Schauble, 2012; Windschitl *et al.*, 2008). Accordingly, students cannot see the value of the models that seek or explain the difference between scientific models and phenomena (Krajcik & Merritt, 2012). Models should be built and modeling practices should be encouraged cumulatively and systemically as opposed to being imparted as if they are a matter of course in which the evidence is completely defined without questions or argumentation in school (Lehrer & Schauble, 2012).

Clement (2008) suggested the co-construction of models for group modeling. This method of modeling allows students to experience the epistemic practice through modeling in the science classroom. Group modeling is a type of learning method that connects Vygotsky's (1978) socioconstructive learning with Rea-Ramirez *et al.*'s (2008) model-based learning. Interaction between small group members can make cognitive conflicts among students who have different cognitive levels and learning tendencies (Kyza *et al.,* 2011). Cognitive conflict within group members can induce students to construct group models through reasoning with other group members (Acher *et al.*, 2007). The reasoning process can be revealed during evaluation and modification of the models (Clement, 2008). As students within groups have different points of view and cognitive abilities, the evolution of models is facilitated by reasoning through cognitive participation. Group modeling through cognitive collaboration can help students understand both the content knowledge of science and the processes of developing and justifying scientific knowledge (Coll *et al.*, 2005). Therefore, group modeling can meet the instructional goals of science education.

The previous studies on models and modeling have focused on analysis of the perceptions or conceptions about models and modeling (Chittleborough *et al.*, 2005; Justi & Gilbert, 2002). Even though some researchers have studied students' models and modeling processes in the science classroom, they only focused on the conceptual change within or learning progressions of individual students (Bamberger & Davis, 2013; Cheng & Brown, 2010; Schwarz *et al.*, 2009; Shen & Confrey, 2007, Tamayo & Sanmartı´, 2007). Recently, some researchers have recognized the epistemic value of group modeling and investigated the reasoning process in group modeling practice (Mendonça & Justi, 2013; Núñez-Oveido *et al.*, 2008; Passmore & Svoboda, 2012). However, it is hard to find out the groups that try to construct their model through interactions between group members with little help from the teacher in these studies.

Students can participate in cognitive processes through critical and reflective interaction among group members during the model co-construction process (Mendonça & Justi, 2013). To put this another way, students reason through argumentation to develop explanations (Sampson & Clark, 2009). *Argumentation* is a communicative activity that scientists engage in when they dispute scientific issues and build scientific theories (Kuhn, 1962). Through argumentation, students evaluate and modify group models by judging the suitability of models and justifying their explanatory models to others (Böttcher & Meisert, 2010). During these processes, individual students try to explain and justify their models for other students' understanding. Therefore, more suitable models can be produced with the agreement of other students (Berland & Reiser, 2009). As argumentation is regarded as an epistemic practice in science, students can experience the epistemological process during group modeling practice.

As students engage in argumentative interaction during the model evaluation phase of a modeling process (Mendonça & Justi, 2013), their epistemological beliefs about science are revealed (Buty & Mortimer, 2008; Oh & Oh, 2011). Of the dimensions of epistemological belief introduced by Hofer and Pintrich (1997), *certainty of knowledge*, *source of knowledge*, and *justification for knowing* can be well presented in model evaluation. In terms of *certainty of knowledge*, students will evaluate models if they perceive the models as tentative and evolving knowledge. Evaluation criteria can differ according to students' belief about source of knowledge. In addition, high-quality models can be generated if students try to justify their knowledge during the model evaluation phase.

Member combinations in a group can decide the group interaction pattern, since each group member has different cognitive and affective characteristics (Richmond & Stirly, 1996). Among those characteristics, learning approaches can be revealed through students' statements and can be a critical element in determining the success of group learning (Chin & Brown, 2000). *Learning approach* refers to the student's tendencies or attitudes as he or she solves learning tasks, and whether he or she attempts to understand associated concepts or relationships (Entwistle, 1981). Students who adopted a deep learning approach generated their ideas more spontaneously, focused on explaining the mechanism, asked questions to request information concerning the mechanism, and evaluated ideas or opinions through reflective thinking (Chin & Brown, 2000). The features of the deep learning approach are similar to features of scientists' practice that emerged during the modeling process. Therefore, it is assumed that the statements of the deep learning approaches can influence group modeling processes.

In this dissertation, group modeling-based inquiry lessons about blood circulation were designed to develop middle school students' modeling abilities through learning by cognitive collaboration. Since the concept of blood circulation is difficult for students to experience or observe directly, it is easy for students to misunderstand (Buckley, 2000; Chi, 2000). Students needed to have comprehensive thinking skills in order to understand the interaction between the functions of elements in the circulatory system and their structures at the cellular, organ, and organ system levels. Therefore, this topic will be appropriate for students whose abilities are different from those of their group members. This way, the students will be able to work together through collaborative group modeling. For understanding the epistemic practice through cognitive collaboration in group modeling-based learning, three studies (chapter III, IV, and V) were conducted.

The study of ‘Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling’ explores the patterns of model development and the factors that led to differences in reasoning among several groups developing one-way circulation models. The patterns of group model development were identified by analyzing the characteristics of interaction. The factors that influenced the reasoning process of group modeling were analyzed into task characteristics and cognitive conflict within a group with the argumentation elements of Toulmin (1958).

The patterns of model development and factors that influenced the reasoning process, analyzed in chapter III, were also found in modeling process of the participants in the study of ‘Epistemological Features and Model Qualities Depending on the Model Evaluation Levels’. Based on these results, it was found that *critical revision* served a core influencing role in the elaborated model development and cognitive conflicts within a group induced high-level reasoning. Both critical revision and cognitive conflicts within groups related to the model evaluation phase, in which diverse students participated in the reasoning process and contributed to model development. In this sense, the study of ‘Epistemological Features and Model Qualities Depending on the Model Evaluation Levels’ aimed to explore epistemological features and model qualities depending on the model evaluation levels and to identify reasoning processes revealed in the highest level of model evaluation.

In the highest level of model evaluation, reasoning processes through cognitive collaboration were well-expressed by statements concerning monitoring one’s own and/or others’ understanding in terms of metacognitive utterances. Based on this finding of the study of ‘Epistemological Features and Model Qualities Depending on the Model Evaluation Levels’, the study of ‘Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling’ aimed to identify the differences of expression of statements of the deep learning approach (SD: Statements of the deep learning approach) according to the features of group modeling activities and to explore cognitive collaboration during group modeling processes focusing on students’ SD

2. Research Questions

This dissertation was designed to identify middle school students' cognitive collaboration as revealed through a small group modeling activity about blood circulation. This would make it possible to identify the value of the small group modeling activity, and to understand the processes of cognitive reasoning and collaborative group learning in small group modeling. Below were the specific research questions for this study.

The study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling' (chapter III) was intended to identify how the patterns of model development were different with regard to model evaluation influenced by science-gifted students' cognitive collaboration, and to explore the factors that influenced on the reasoning process of elaborated model development. Hence, the research questions were as follows:

I-1. What are the patterns of model development in group modeling?
I-2. Which factors cause a difference in reasoning during group modeling?

The study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' (chapter IV) aimed to understand the model evaluation process by analyzing the middle school students' epistemological features in model evaluation on blood circulation. The research questions were:

II-1. What are the epistemological features and model qualities depending on model evaluation levels?

II-2. What reasoning processes are revealed through a high-level of model evaluation?

The study of 'Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling' (chapter V) assumed that learning approaches could be crucial to both individual learning and group learning processes. With this assumption, the relationship between the statements of the deep learning approach and group modeling processes was analyzed. The research questions were outlined below:

III-1. What differences are there in the way the statements of the deep learning approach is expressed based on the features of each group modeling activity?

III-2. What effect do the statements of the deep learning approach have on cognitive collaboration and model development during the small group modeling process?

3. Research Overview

Figure I-1 shows the overall research design. First, a literature review was conducted. This review included several ideas such as models and modeling in science education, models and modeling of blood circulation, cognitive reasoning in modeling, and the approaches to learning science in collaborative modeling.

In the study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling' (chapter III), fourteen science-gifted middle school students participated in group modeling about one-way blood flow in the heart. For identifying the patterns of model development and the reasoning process, participants engaged in a group modeling lesson about one-way blood flow in the heart.

In the study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' (chapter IV), 34 middle school students participated in model-based learning consisting of three lessons. Students drew blood circulation diagrams as group models. This research was conducted to identify epistemological features according to the model evaluation levels and the context of the highest level of model evaluation.

In the study of 'Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling' (chapter V), four students among participants in the study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' (chapter

IV) were selected for the case study. This was because their model was close to the target model and showed dialogic interaction patterns. The lessons consisted of three modeling-based activities, and the target model was blood circulation. The group members' collaborative cognitive processes, and model development in the group modeling activities, were investigated.

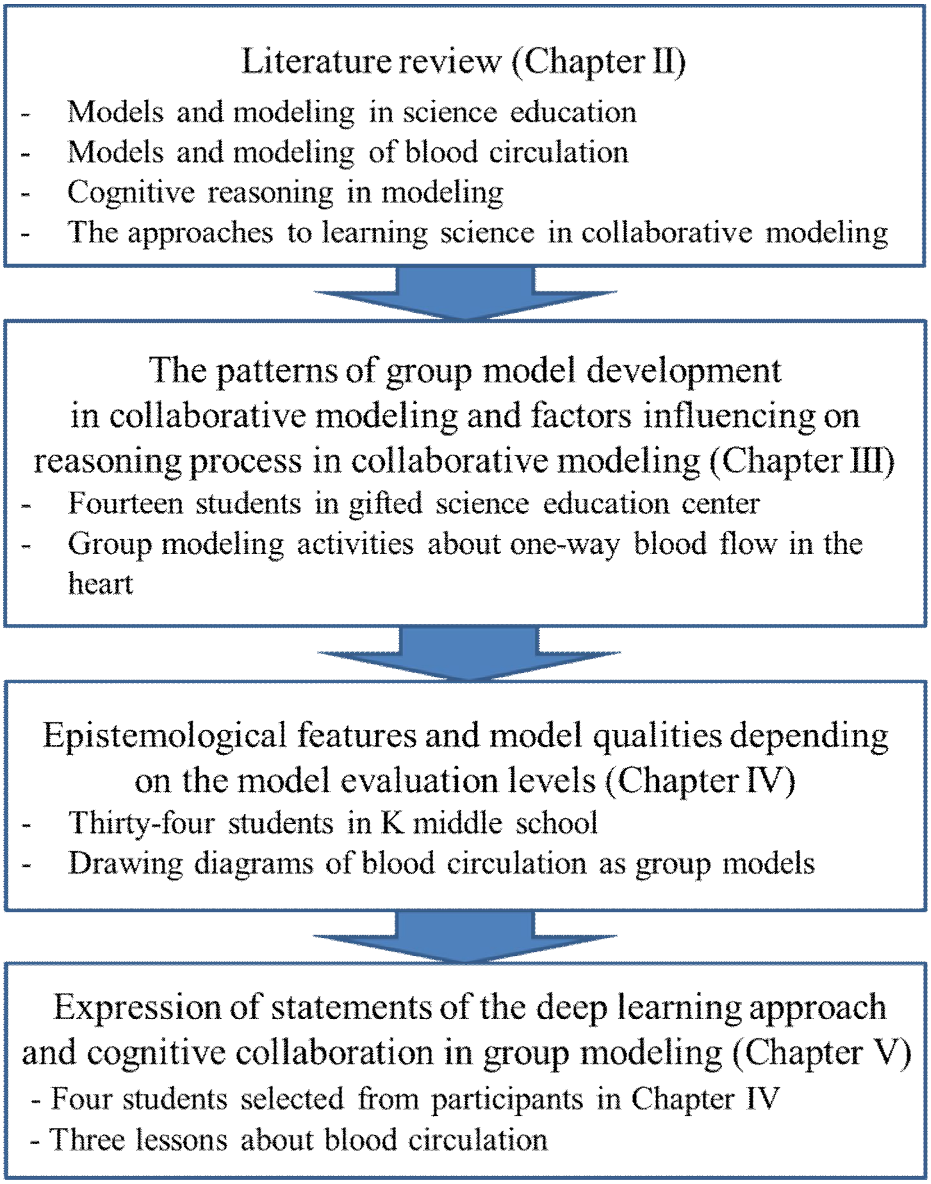

Figure I-3. Research overview

4. Definitions of Terms

Some specific terms used in this study can be defined as follows.

4.1. Model

Researchers employ various definitions of models, including the following: simplified representations for explaining and predicting phenomena (Harrison & Treagust, 2000; Passmore & Stewart, 2002; Schwarz *et al.*, 2009); consensus models based on scientific theories (Clement, 2008; Treagust *et al.*, 2002); links between abstract theories and specific experiments (Gilbert *et al.*, 2000). Although definitions of models vary from author to author, one thing they have in common is that they define models as explanatory representations of natural phenomena or of systems using objects, languages, behaviors, and so forth. In this study, the most common definition of a model is adopted

4.2. Modeling

Modeling usually refers to the process of constructing the models and has the repetitive process of generating, evaluating, and modifying the intermediate models until becoming the final models. Clement (1989) called this process of evolving the initial models as GEM cycle. According to this definition, modeling is defined as the development process of generating, evaluating, and modifying the explanatory models representing the phenomena or natural systems in this study.

4.3. Group Model

In a sociocultural perspective, models created by scientists are evaluated, modified, and elaborated through argumentative interactions until they are accepted by peer scientists. Likewise, students also need to interact with each other to reason collaboratively for constructing models. In this study, group model is defined as the models constructed through group interaction.

4.4. Group Modeling

Group modeling is defined as the process in which students develop group models through interactions between group members. During group modeling, students in each group co-construct group models via tacit or explicit agreement.

4.5. Cognitive Collaboration

Students who have higher cognitive abilities provide scaffolding to others during group activities because of differences in the levels of students' actual and proximal development (Vygotsky, 1978). Some students do not just provide cognitive scaffolding; they also criticize and modify the opinions of others by engaging in critical monitoring (Oliveira & Sadler, 2008). In this study, cognitive collaboration is defined that several students participate in reasoning process of group tasks and give a cognitive help to each other. It is categorized into cognitive scaffolding and critical monitoring. Students understand from participating in small-group activities that different individuals have different views and knowledge bases. Furthermore, they are able to construct models, which are close to the target models, through cognitive collaborations with others than the models they create on their own.

4.6. Epistemological Features

Epistemology is an area of philosophy concerned with the nature and justification of human knowledge (Hofer & Pintrich 1997, p. 88). In other words, it is the answer to the questions like "what is knowledge?" or "how do we gain knowledge" (Grayling, 1996, p. 37). Former researchers used the interview or questionnaire methods for detecting students' epistemologies. They just used the observation of students' performance in lesson as the supplementary data supporting the interview or questionnaire methods. However, the students' performance (utterances and actions) in lessons were the main data for identifying students' epistemologies in this study. Epistemological features refer to reasoning process, in which students construct or justify models, expressed as the form of utterances or actions.

4.7. Statements of the Deep Learning Approach

Learning approach refers to the student's tendencies or attitudes as he or she solves learning tasks, and whether he or she attempts to understand associated concepts or relationships (Entwistle, 1981). In particular, students who use deep learning approaches tend to be motivated by *inner interest* or by an *intrinsic motivation* and they apply an in-depth strategy that connects their prior knowledge to the learning materials (Biggs, 1993). Chin and Brown (2000) conducted a qualitative analysis of students' learning strategies when they engaged in hands-on investigations. Students who adopted a deep learning approach generated their ideas more spontaneously, focused on explaining the mechanism, asked questions to request information concerning the mechanism, and evaluated ideas or opinions through reflective thinking. They also persisted in following up on an idea with some sustained interest before moving to another one. The statements of deep learning approach is defined that above five characteristics of learners having deep learning approach are expressed by statements during modeling-based instructions.

Ⅱ. THEORETICAL BACKGROUNDS

In this chapter, the literature concerning models and modeling in science education, models and modeling of blood circulation, cognitive reasoning in modeling, and the approaches to learning science in collaborative modeling provided for this research with fundamental rationales will be reviewed.

1. Models and Modeling in Science Education

In this section, models and modeling will be defined, and collaborative modeling and the roles of models and modeling described.

1.1. Models in Science Education

Scientific knowledge enables one to understand natural phenomena, components, and causal relationships of phenomena. Scientists construct models to represent and simplify complex phenomena, since it is often impossible to develop an explanation of the phenomena themselves (Giere, 1999; Gilbert *et al.*, 2000; Morrison & Morgan, 1999; Nersessian, 1999). Models can provide the means for scientists to investigate natural phenomena, because models visualize the phenomena or experiences for a better understanding, and to more easily search for possible solution while designing the research problems (NRC, 2010). First of all, models will be defined and its classification and mode of representation depicted.

1.1.1. Definitions of models

In science education, many researchers define a model differently; however, they have certain things in common. The National Science Education Standards (NSES) emphasize the role of models in the science classroom, and define models as the tentative structures or schemes corresponding to real objects and events, which possess explanatory power (NRC, 1996). Similar to the NSES definition, other researchers also emphasize the fact that models are the explanatory systems representing the natural phenomena or systems in common. Harrison and Treagust (2000) and Ingham and Gilbert (1991) suggest that models represent parts of specific aspects, or the key features, in natural phenomena or systems.

Some researchers define models as mediators between the students' understanding and the explanation of the real natural world. Acher *et al.* (2007) define models as "intermediaries between children's capacity of interpreting natural facts and the multiple aspects of these facts that substantially work by representing hidden semantic connections and organizing them in a comprehensive meaning" (p. 399). Gilbert and Osborne (1980) refer to models as intermediates in the learning process and teaching assistant method, providing a figurative representation. Gilbert and Boulter (1998) emphasize that models are instructional tools by explaining that models are the connection between the abstraction of theories and concrete activities of experiments.

Several researchers have added prediction to the definition of models as the explanation of phenomena. Schwarz *et al*. (2009) describes models as “representations that abstract and simplify a system by focusing on key features in order to explain and predict scientific phenomena” (p. 633). Passmore and Stewart (2002) define the scientific model as the idea set for describing the natural process, which operates mentally and restrictively for explaining or predicting phenomena. Halloun (2004) explains that models serve an explanatory function containing pattern descriptions, explanations, post-diction, and prediction.

Other researchers emphasize communicating with others in defining models; for example, Lehrer and Schuable (2012) define models as expressions that function as arguments explaining natural phenomena in terms of tools for communicating. According to their definition, people, even novice scientists, can construct models for explaining their understanding and communicating their ideas with others. Windschitl *et al*. (2008) insist that models can present theoretical structures and reflect the scientific process and knowledge to support activities and discourse within scientific communities. They suggest that one important feature of models is to create and communicate the models, just as a scientist’s work.

1.1.2. Classification of models and modes of representation

Gilbert *et al*. (2000) classified models with an ontological status, and explained the five modes of representation respectively (Tables II-1 and II-2). The ontological status of models in this study was arranged using four kinds of scientific knowledge (Figure II-1). In general, *researchers' scientific knowledge* may be incomplete and therefore the agreement of the science community is needed. If the models representing the *researchers' scientific knowledge* become *established scientific knowledge*, then these models can be called consensus models or scientific models. In order to teach scientific models, *established scientific knowledge* should be selected and simplified. In this sense, *taught scientific knowledge* can be called curricular models. As the understanding of consensus, historical, and curricular models is often difficult, teaching models are developed to assist the learning and teaching process by either a teacher or student (Gilbert *et al.*, 2000). During this study, students engaged in three lessons based on group modeling activities. The students constructed the models actively based on their inquiry experiences and background knowledge. They did not learn scientific knowledge from the teacher's instruction or developed models but rather from their modeling practice. Therefore, the ontological status of models in this study is situated between *established scientific knowledge* and *learnt scientific knowledge* (Figure II-1).

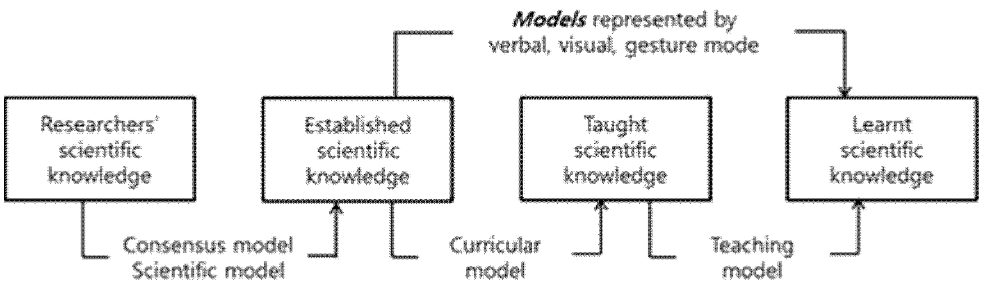

Figure II-1. Ontological status of models in this study

Table II-1. Classification of the ontological status of models (Gilbert *et al.*, 2000, p.12)

Classification of models	Description
Mental model	· Private and personal cognitive representation · Formed by an individual either on their own or whilst within a group
Expressed model	· Placed in the public domain but an individual or group, usually for others to interact with, through the use of one or more modes of representation · The relation between mental model and expressed model is complex. Expressing mental model changes it
Consensus model	· Different social groups, after discussion and experimentation, can come to an agreement that an expressed model is of value, thereby producing it. · An expressed model which has gained acceptance by a community of scientists following formal experimental testing, as manifest by its publication in a referred journal, becomes a scientific model.
Historical model	· Consensus model produced in specific historical contexts and later superseded for many research purposes
Curricular model	· The version of an historical or scientific model which is included in a formal curriculum, after some further simplification
Teaching model	· As the understanding of consensus, historical, and curricular models is often difficult, teaching model are developed to assist in that process. · Developed by either a teacher or by a student

(*Continued*)

Table II-2.
(*Continued*)

Classification of models	Description
Hybrid model	· Formed by merging some characteristics of each of several distinct scientific, historical, or curricular models in a field of enquiry · Used for curriculum and classroom teaching purposes as if it were a coherent whole
A model of pedagogy	· Used by teachers during the planning, practical management, and reflection on, classroom activity · Concerned with the nature of science, the nature of science learning

Table II-3. Modes of representation (Gilbert *et al*., 2000, p.13)

Modes of representation	Description
Concrete mode	Consist of the use of materials
Verbal mode	Consist of the use of metaphors and analogies in speech and in written form
Mathematical mode	Consist of mathematical expressions, including equations
Visual mode	Make use of graphical pictorial forms in graphs and in diagrams
Symbolic mode	Include visual, mathematical, and verbal mode
Gesture mode	Consist of actions

Meanwhile, models in this study were categorized as mental, expressed, or consensus models as defined by Gilbert *et al*. (2000). Students constructed their mental models using group interactions, and these mental models were revealed as expressed models by discourse, writing, and diagrams. These expressed models became the group models as consensus models, which were formulated by agreement through the students' discourse. These models used in this study could be explained with the diagram in Figure II-2 which was drawn by Chittleborough *et al*. (2005).

Figure II-2 shows the relationships between teaching, scientific, mental, and expressed models, and explained students' learning and understanding. Mental model are defined as the representation of phenomena that are constructed internally by students (Johnson-Laird, 1983), and expressed models are the forms of mental models that are revealed individually through actions, voice, and writing. Scientific models are authorized socially because they are tested and judged to be valuable by scientists (Treagust *et al*., 2002), and defined as representations of scientific phenomena focusing on core aspects for explaining and predicting, which simplify and abstract (Harrison & Treagust, 2000). Teaching models are specially constructed models that teachers use to help students understand scientific concepts. Figure II-1 shows the developing process of students' mental models in learning. Learning includes evaluating or integrating scientific knowledge with students' metacognitive frameworks, and is revealed as expressed models.

In this study, siphon pumps, as teaching models, were provided to the students for forming their mental models and revealing their expressed models. The students constructed group models based on the experience of manipulating the siphon pump and their background knowledge. The students might have acquired their background knowledge from the previous learning experience, which was supported by the scientific knowledge. In addition, students' mental models were represented by verbal mode through speaking and writing, visual mode (such as a blood circulation diagram), and gesture mode (such as using hand-motion or tools for expressing their mental models). Then the models were compared to the target models with the author's analysis of students' discourse, actions, diagrams and writings on the worksheets.

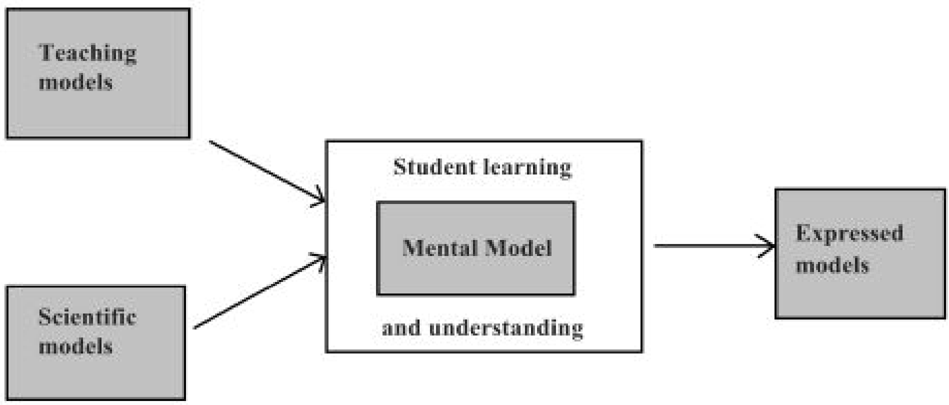

Figure II-2. Theoretical framework of models in learning (Chittleborough *et al.*, 2005, p.197)

1.2. Modeling in Science Education

Modeling is a dynamic process of constructing and developing models, and it is regarded as the essential process of building scientific knowledge by scientists (Justi & van Driel, 2005). Modeling practice is one of the main activities for encouraging students to participate in scientific activities and the thinking process (Krajcik & Merritt, 2012). Many science education researchers define modeling differently, but they also agree that modeling is made up of three processes: generating models, testing or evaluating the validity of the models reflectively and critically, and modifying the models closely to the scientific concepts.

Clement (1989) viewed the small modeling cycle as the evaluation process in which students and the teacher, or just students, work together to develop the model, and they presented the GEM cycle, which emphasizes the initial model's evolutionary process (Figure II-3). In this cycle, the students first produce an initial model, applying their knowledge in the model generation phase. Next they evaluate the initial model to see if it explains the scientific phenomena in the model evaluation phase. Finally, the students revise and modify the model in order to make them almost the same as the target model in the model modification phase.

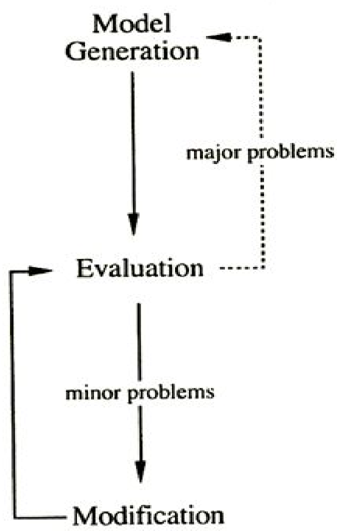

Figure II-3. GEM cycle (Clement, 1989)

Many researchers emphasize the process of using and applying models in model evaluation phase because these can test the explanatory power of the models (Acher *et al.*, 2007; Buckley, 2000; Halloun, 1998; Harrison & Treagust, 2000; Schwarz *et al.*, 2009). Justi and Gilbert (2002) analyzed scientists' modeling and insisted that model evaluation was represented in the model of the modeling framework, and that model evaluation can be conducted by thought experiments and empirical tests during modeling.

Model testing is also conducted in the science classroom during the modeling-based lesson, and the students perform model testing by discussing the suitability of the models using present evidence (Mendonça & Justi, 2013). This process may be important because previous mental models can be rejected or revised at this stage. If the models are not in agreement with the evidence suggested by thought experiments or empirical tests, the explanatory power of the models get weaker. Therefore, students can do cognitive reasoning, individually and between students, to judge and enhance the models.

1.3. Collaborative Modeling

1.3.1. Social interaction in collaborative modeling

Learning, which is viewed as meaning making, occurs through classroom discourse between teachers and students, as well as between students in the science classroom (Hicks, 1995; Mortimer & Scott, 2003). According to Vygotsky (1978), students interact with each other by means of an internal psychological plan using language as a medium. They identify other's views and construct a common meaning when different opinions are presented. The zone of proximal development (ZPD) is defined as the distance between the actual developmental level (ADL), as determined by independent problem solving, and the potential developmental level (PDL), which is determined through adult or peer guidance. As students have different ZPD, students with higher ADL may assist their peers with a deeper understanding through classroom discussions. Accordingly, peers with a different understanding may encourage others' participation in the cognitive collaboration process by criticizing and questioning their peers' opinions within their ZPD. Thus, a more complete understanding may result from the collaborative learning process than from individual learning. In the collaborative environment, scaffolding, which is a cognitive assist within a ZPD, may take place and allow students to express their opinions freely through small group modeling (Hogan & Pressley, 1997).

Collaborative learning is supported through meaningful verbal interactions between students during small group activities. For example, Bell and colleagues claimed that collaborative inquiry learning arouses students' interests and motivations in science, and students gain a knowledge of scientific processes, similar to those that scientists use (Bell *et al.*, 2010). Buty and colleagues suggest that verbal interactions between students provoke the development of meta-knowledge functioning in judgment of the suitability of knowledge (Buty *et al.*, 2010). In addition, Richmond and Striley (1996) define the scientific inquiry discussion occurring in the science classroom as the social norm. They argue that these interactions both positively and negatively influence each student's scientific knowledge building. In this regard, peer discussions may foster the effectiveness of small group modeling. This is because students could improve both cognitive and metacognitive skills during the creation of their own models, and while criticizing other models (Coll *et al.*, 2005).

Composition of group members is critical for collaborative learning.

Richmond and Striley (1996) categorize the roles of group members, and identify their interactions based on the roles of the group members. The social roles of the students are defined as leader, helper, and noncontributer (active/passive). Leaders, especially, construct arguments in group activities, and serve important roles in social interactions while building knowledge. Leaders are classified into three styles: inclusive, persuasive, and alienating. Table II-3 shows leaders' intellectual and social characteristics.

Inclusive leaders construct scientifically correct arguments based on the synthesis of member attributions, and distribute work and credit among group members. Persuasive leaders persuade others to accept the right answer and get others to follow their lead. Alienating leaders prove that they are right and demonstrate intellectual superiority. Teachers should assist argumentation for requiring the shared responsibilities in group presentations and accomplishing individual projects. The teacher facilitates students who have lower status to participate in group activities by supporting the abilities needed for a specific task; however, a teacher's role is limited in group interactions. Therefore, group leaders are critical for success in group modeling. The leader styles identified by Richmond and Striley (1996) are one of the factors that influence the classification of patterns of model development in the study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling' (chapter III).

Table II-4. Student leadership styles and associated goals (Richmond & Striley, 1996, p.856)

Style	Intellectual	Social
Inclusive	Scientifically correct argument based on synthesis of member attributions	Distribution of work and credit among group members
Persuasive	Persuade others to accept the right answer	Get others to follow their lead
Alienating	Prove that they are right	Demonstrate intellectual superiority

1.3.2. Model co-construction in collaborative modeling

Models can be developed gradually based on evidence in group modeling. Rea-Ramirez and colleagues described how the modeling process develops gradually through cognitive collaboration when students engage in small group activities (Rea-Ramirez *et al.*, 2008). Figure II-4 shows the learning pathway suggested by these authors, who were inspired by Piaget's theory of cognitive development, in which learning occurs to solve dissatisfaction due to the differences between the initial concepts and the target concepts. During this process, the current model cannot suddenly change to the target model. Instead, modeling can be regarded as a co-construction, requiring several people's participation. The initial model develops into the target model through a series of criticisms and revisions throughout the process of model co-construction. Models that are not appropriate compared to the criteria, are discarded or revised (Passmore & Stewart, 2002); therefore, cognitive interaction judging the suitability of the models is needed for group modeling, and group models can be developed into the target model.

A series of intermediate models create during the development process involves a cycle of generation, evaluation, and modification of models. Among these three phases, the evaluation and modification phases are the results of the dynamic interactions between the students. Cognitive collaboration is especially evident in these two phases. Accordingly, intermediate models are multiple, and the greater the students' cognitive participation, the more intermediate models there are. The participants in this study performed the group modeling through this modeling-based learning pathway (Figure II-4).

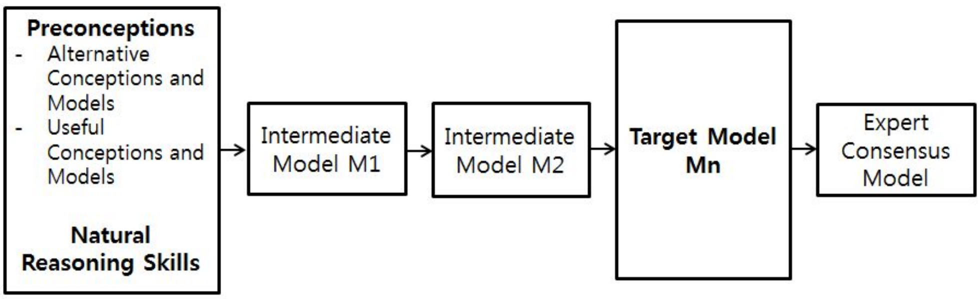

Figure II-4. Learning pathway in model-based learning (Rea-Ramirez *et al.*, 2008)

Small group modeling processes present group members with the opportunity to not only share their knowledge or models on the social level, but also collaboratively test and revise their models via discourse. The process of model-based inquiry learning is that individual mental models are integrated after receiving critical revision and modification, becoming group models by adding several individual models. Finally, these group models become individual models again after the students' internalization of group models.

1.4. The Roles of Models and Modeling

Gilbert *et al*. (2000) identified three contributions of models and modeling in science education. First, creating mental models and external representations of expressed models help students to develop their understanding. Second, students can experience the process of science by generating expressed models and conducting empirical tests. Third, historical models and scientific models are the main products of science, and objects for students' understanding.

Hodson (1993) categorized the main goals of science education as *learning science*, *learning about science*, and *learning to do science*. *Learning science* is the process of understanding the main works, concepts, models, and theories of science. *Learning about science* is developing an understanding of nature and the ways of science. *Learning to do science* includes participation in the scientific inquiry practice, and the development of expertise. These goals are consistent with the claims of Gilbert *et al.* (2000); for example, *learning about science* and *learning to do science* mean that students can participate in the process of modeling through the testing of models and modeling, and they can develop their understanding what they want to know and the nature of models and modeling. *Learning science* among the goals of science education suggests an understanding of historical and scientific models as curricular models.

In other words, *learning about science* among the main goals of science education can be achieved by engaging in modeling practice. This is because students' modeling is similar to scientists' works so that the students can experience epistemic practice. Many researchers argue that students can acquire the goal of *doing science* by interacting with others in science inquiry lessons (Gilbert *et al.*, 2000; Sensevy *et al.*, 2008; Windschitl *et al.*, 2008). Epistemic values of modeling-based inquiry are elaborated by Windschitl *et al.* (2008), who identified five epistemic features of scientific knowledge that correspond with model-based inquiry and inquiry as commonly practiced (Table II-4). In the model-based inquiry, students can experience five epistemic features of scientific knowledge. For example, students can construct an argument for justifying the initial models based on evidence that is collected for explaining phenomena, and a result, students experience *doing science* by engaging in the modeling process.

Table II-5. Five epistemic features of scientific knowledge in model-based inquiry (Windschitl *et al*., 2008)

Five epistemic features of scientific knowledge	Epistemic operation in model-based inquiry
Testable and Revisable	· Ideas in the form of models are tested and revised · Accomplished by evaluating hypotheses that make sense within context of a potentially explanatory model.
Explanatory	· Uses patterns in data, other sources of evidence to explain why focal phenomenon happens · Models talked about as tools for explanation.
Conjectural	· Explanations account for observations with underlying, often unobservable causal processes, or structures.
Generative	· Models/theories used to generate plausible hypotheses, new conceptions, new predictions at any point in the inquiry.

2. Models and Modeling of Blood Circulation

The model is widely used in many fields of science, including chemistry, physics, earth science, and biology. Every discipline of science have aim to construct, evaluate, revise, and predict models of natural phenomena (Giere, 1999; Hesse, 1962). They, however, have different way of modeling (Lehrer & Schauble, 2012). For example, the principles of chemistry deal with microparticles and their activities and interactions—ideal objects for representations and models (Oversby, 2000). Physics turns to models in its need to explain “the way the world works” (Rutherford 2000, p. 254). In the case of earth science, cosmic phenomena or changes in the earth can be described using models. The phenomena of biology also have been explained using models because a greater number of specific laws and concepts exist in biology compared to other branches of science, and living creatures are integrated in a complicated and compositive system that has many interacting parts at the levels of the molecule, cell, organ, and organism (Cartwright, 1999; Verhoeff *et al.,* 2008).

Blood circulation among biology concepts is not imaginable because of its invisibility. For this reason, both students and teachers experience a strong challenge when attempting to understand blood circulation (Arnaudin & Mintzes, 1985; Buckley, 2000; Chi, 2000; Pelaez *et al.*, 2005; Yip, 1998). Several studies on the analysis of students’ mental models have been carried out in order to understand and avoid misconceptions about blood circulation in the field of science education (Arnaudin & Mintzes, 1985; Chi *et al.,* 1994; Pelaez *et al*., 2005). For example, in a study done by Arnaudin and Mintzes (1985), the authors selected a total of 495 students from the fifth, eighth, and tenth grades as well as college freshmen; the students were asked to explain and describe blood circulation. This process revealed the misconceptions students held regarding the structure and function of both the blood and the heart, circulation patterns, the relationship between circulation and respiration, and also the closed-circulatory system. Their misconceptions about the latter three concepts, which are unapproachable and complicated, were not easily changed. Another study done by Chi *et al*. (1994) revealed that students had difficulties when they were asked to construct a complete and correct circulation system model regarding the source of oxygen, the purpose of lungs, and the number of loops, and the numbers of circulation cycles. In particular, although some students viewed the circulatory system as a double loop model, they could not explain how each component works. This meant that they were not able to explain the entire system without missing the details, even though they could have a correct model in terms of the flawed mental model. Moreover, Pelaez *et al*. (2005) claimed that prospective elementary teachers had misconceptions about blood circulation pathways and gas exchange, and their misconceptions could not be easily changed.

Students' misconceptions of blood circulation might be derived from their perception of ontological categories to the phenomena. Chi

(2005) viewed the ontological category of blood circulation as a "direct process", and she claimed students' misconceptions of "direct process" might be nonrobust compared to the conception of diffusion, which entails the new effect created by individual components of a process having indirect impact on the overall process and was categorized as an "emergent process". In the case of blood circulation, components of the heart have a direct influence on the direction and speed of blood flow, explaining its categorization as a "direct process". However, circulation also can be viewed as an "emergent process" due to the dynamics and its intrinsic randomness (Buckley, 2000; Kim & Kim, 2006). That is, blood circulation has a dynamic mechanism because of the gas exchange principle in each organ; the way in which blood is transported to each organ is random; and blood circulation proceeds with the constant interactions among the mechanisms of heart, vessels, and blood. These properties associated with an emergent process can easily cause students' misconceptions about blood circulation.

The findings of these previous studies gave us insights into developing a better way to understand and collect students' models. To minimize and identify students' misconceptions about blood circulation, students should engage in hands-on activities. The lesson in the study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling' (chapter III) and the first two lessons in the study of of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' (chapter IV) and the study of 'Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling' (chapter V) were designed to help them understand the basic concepts for modeling overall blood circulation: the structure of the heart, the heart structure for preventing the mixing the oxygenated blood with the deoxygenated blood, the mechanism of one-way blood flow in the heart, and the pumping role of the heart. In this way, students could better understand the heart's structures and functions. The diagram-drawing task, which has been proven to identify students' misconceptions in the previous study (Chi *et al*., 1994), was arranged as a group activity in the third lesson in the study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' (chapter IV) and the study of 'Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling' (chapter V). Students' individual models and group models could be revealed when they tried to draw a diagram through verbal interaction.

The previous studies on blood circulation models tried to explain what students' models are and why their misconceptions are so robust. However, this dissertation focused on the sociocultural point of view. Núñez-Oveido and his colleagues explored students' modeling processes regarding blood circulation with the help of the teacher from a sociocultural perspective (Núñez-Oveido *et al,* 2008, pp. 179-183). Unlike Núñez-Oveido and colleagues' study, this study aimed to examine the cognitive interactions among students and how they expand in group models, rather than model development under the control of the teacher.

Small-group activities enable students to express various ideas and opinions through their discourses. When students engage in small-group modeling activities, various individual opinions, and evaluations and justifications of these opinions, emerge during this process: ideas are presented and criticized, and students must defend them with evidence (Böttcher & Meisert, 2011). These argumentation activities lead to the metacognitive monitoring activities that help each student modify his or her own understanding and the understanding of others (Nelson & Narens, 1994). Significantly, small-group modeling activities provide more chances to develop models in a positive way as compared to individual modeling activities. Therefore, students' epistemological features were focused on in terms of justification processes in small-group modeling.

3. Cognitive Reasoning in Modeling

3.1. Practical Epistemology Revealed in Model Evaluation

In general, students are asked to engage in scientific inquiry with the goals of learning scientific materials and concepts and of gaining knowledge about the nature of science by taking part in the work that scientists do. In spite of the great emphasis on the importance of scientific inquiry in standard educational documents (NRC, 2000), students hardly experience the epistemic features of scientific knowledge in science classroom emphasizing the scientific method (Windschitl *et al.*, 2008). Many authors suggest modeling-based inquiries to overcome the current difficulties in school science (Clement, 2000; Gobert & Buckley; 2000; Windschitl *et al.* 2008). Model-based inquiry is a learning strategy that helps students construct mental models when they practice a specific learning task, rather than merely using models as instructional materials (Gobert & Pallant, 2004).

When students engage in modeling activities, they experience model construction, evaluation, and modification processes that are quite similar to scientists' work. During these processes, their epistemological beliefs could be explored; this is related to practical epistemology (Bell *et al.*, 2010). The hypothesis of practical epistemology is based on the fact that engagement in modeling activities can enhance epistemological knowledge development (Sandoval, 2005), and this epistemological knowledge is called *metamodeling knowledge* (Schwarz & White, 2005). Schwarz *et al.* (2009) proposed a learning progression that reflects the interaction between modeling practices and metamodeling knowledge. This learning progression includes two dimensions—the generative nature of models as tools for explaining and predicting, and the dynamic nature of models as improving with new understanding. One type of learning progression, "the dynamic nature of models as improving with new understanding" (Schwarz *et al.*, 2009, p. 209), reflected students' epistemological features, which were related to understanding the changeable nature of models, evidence of model evaluation such as authority, superficial composition, and explanation to the phenomena, and justification based on evidence. These epistemological features support the ideas of certainty of knowledge related to the nature of knowledge, and sources of knowledge and justification for knowing related to the nature of knowing, which was addressed by Hofer & Pintrich (1997). They tried to emphasize that students should be aware of the fact that knowledge is uncertain, and it can be developed through the interactions with other people concerning the process of knowing.

It is important to note that practical epistemological features of science are well presented during model evaluation process (Buty & Mortimer, 2008; Oh & Oh, 2011). Students' modeling evaluation processes involve both evaluative epistemology (Kuhn, 1991, p. 188) that claims there is no certain knowledge, and model justification processes that justify the models using proper evidence. This indicates that the modeling evaluation process reflects practical epistemology (Buty & Mortimer, 2008; Gobert & Pallant, 2004; Oh & Oh, 2011; Schwarz *et al.*, 2009). In particular, small-group modeling activities enable students who have different knowledge bases to express their own opinions on the social plane. When students faced cognitive conflicts within a group caused by different opinions, they tried to evaluate models using various criteria and justify the models whether they agreed or disagreed with each other concerning what the model should explain about the phenomena, a process that finally resulted in clarity of ideas and concepts (Sandoval & Reiser, 2004). This argumentation process not only provides an opportunity to develop epistemic criteria, but could also lead to production of higher-quality models (Böttcher & Meisert, 2010). In fact, students' argumentation makes it possible to enhance the quality of reasoning and modify the models by persuading others and justifying their own opinions. In other words, the model evaluation process is a critical phase because students' practical epistemologies can be well presented in this phase.

The study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' (chapter IV) examined the levels of students' model evaluation during the modeling processes, and further developed a framework that reflects their epistemological features (Table IV-1). In addition, the learning progression concerning "the dynamic nature of models as improving with new understanding” (Schwarz *et al.*, 2009, p. 209; Table II-5) was applied to model evaluation levels in study of ‘Epistemological Features and Model Qualities Depending on the Model Evaluation Levels’. The criterion of evaluation levels focuses on the evidence students used during the evaluation processes, and Level one to three were adapted for developing the framework for “Levels of model evaluation and epistemological features” (Table IV-1). The levels were classified under consideration according to whether they used evidence from authoritative sources and whether they represented models on the superficial level or on a level that required deeper understanding. Moreover, the epistemological features were inductively concluded by focusing on the reasoning processes students used to justify their opinions and develop their models.

Table II-6. Evaluation criteria according to the performances of a learning progression for understanding models as changeable entities

Level	Performances (Schwarz *et al*., 2009)	Evaluation criteria
1	Students do not expect models to change with new understandings. They talk about models in absolute terms of right or wrong answers.	
2	Students revise models based on information from authority (teacher, textbook, peer) rather than evidence gathered from the phenomenon or new explanatory mechanisms.	Information from authority
	Students make modifications to improve detail, clarity or add new information, without considering how the explanatory power of the model or its fit with empirical evidence is improved.	Superficial component of models
3	Students revise models in order to better fit evidence that has been obtained and to improve the articulation of a mechanism in the model. Thus, models are revised to improve their explanatory power. Students compare models to see how different components or relationships fit evidence more completely and provide a more mechanistic explanation of the phenomena.	Comprehensive criteria related to the explanatory nature of the models
4	Students consider changes in models to enhance the explanatory power prior to obtaining evidence supporting these changes. Model changes are considered to develop questions that can then be tested against evidence from the phenomena. Students evaluate competing models to consider combining aspects of models that can enhance the explanatory and predictive power.	Predictive power of the models

3.2. Argumentation in Model Evaluation

Argumentation is invaluable for scientists as a way of communicating with each other, building scientific knowledge, and solving controversial issues (Kuhn, 1962). To justify their assertions, scientists have to engage in argumentation within the science community. In other words, it plays an important role in the process of generating scientific knowledge. Their scientific knowledge should be examined, revised and justified, which will ultimately result in its theoretical base becoming more stable. A similar situation applies in model-based inquiry in the science classroom, based on students' verbal interaction (Berland & Reiser, 2009; Böttcher & Meisert, 2011; Bricker & Bell, 2008; Campbell *et al.*, 2012; Sampson & Clark, 2011).

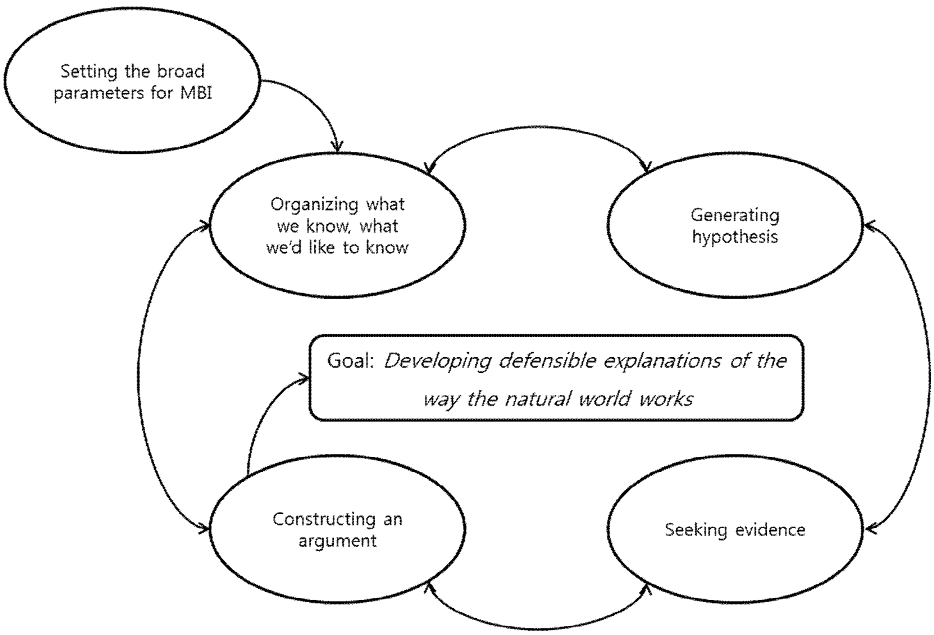

Figure II-5. The four interrelated conversation supporting model-based inquiry (Windschitl *et al.*, 2008, p.955)

Windschitl *et al.* (2008) also emphasize the argumentation as the course to develop explanations of the way the natural world works (Figure II-5).

The evidence yielded by empirical experiences is not used just for generating models. Although a model introduced for the first time could give a perfect explanation of a certain phenomenon, this would merely be luck and the possibility of it happening is slim. Models created by scientists are evaluated, modified, and elaborated through argumentative interactions until they are accepted by peer scientists. Likewise, students also need to interact with each other to reach the goals of sense-making and engaging in articulation of their thoughts and persuasions when explaining phenomena (Berland & Reiser, 2009). According to Berland and Reiser (2009), the above three discourse goals are defined as follows: students explain phenomena by connecting evidence and assertions, which can be viewed as *sense-making*; *articulating* refers to the expression or communication of explaining the phenomena; and *persuading* is a social process, since it considers the validity of various ideas delivered by many people in order to find the most appropriate explanation.

These three goals of scientific practice—*sense-making, articulating*, and *persuading*—can create the context of argumentation and can also explain the appropriateness of the social process in modeling. Models are gradually developed as a result of a cyclic process involving model generation, evaluation, and modification (Clement, 2008). During this modeling process, students generate evidence-based models through sense-making, and articulation and persuasion allow for argumentative interaction as the evaluation of the strengths and weaknesses of the models or ideas generated by the group (Passmore & Svoboda, 2012). Students with various knowledge bases act as scaffolding for each other, allowing all to participate in cognitive collaboration by critically monitoring each other's opinions through cognitive interactions. In this way, reasoning processes become sophisticated and modeling can eventually progress through model generation, evaluation, elaboration, and modification (Mendonça & Justi, 2013).

It is important to note that these types of modeling features should be reflected in school science; however, it is mainly teachers who lead cognitive reasoning processes when students engage in small-group modeling activities. Cognitive collaboration in modeling has been explored between teachers and students only—that is, the teacher provides question prompts and clues containing scientific knowledge and critically evaluates students' models (Mendonça & Justi, 2013; Núñez-Oveido *et al.*, 2008; Passmore & Svoboda, 2012). However, while students sometimes need help from teachers when in difficulty, some groups may try to construct their model through interactions between group members with little help from the teacher. Students who engage in cognitive collaborations with group members could be seen as the ones who actually experience small-group modeling, and those students eventually have authentic cognitive experiences (Lee & Kim, 2013).

4. The Approaches to Learning Science in Collaborative Modeling

Why are some students better at learning? Do they acquire more and/or deeper knowledge? The best answer to these questions is that they experience different practices during the learning process that improve their ability to learn by varying degrees. A number of researchers have tried to investigate practice processes in terms of individual characteristics especially learning approaches with an eye toward explaining the variable levels of academic achievement among students (Biggs, 1993; Cano, 2005; Case & Gunstone, 2002; Chiou *et al*., 2012; Chiou *et al*., 2013; Entwistle 1981; Säljö, 1979). Although researchers have proposed many different kinds of learning approaches, *deep* and *surface* approaches are the most common (Biggs, 1993; Entwistle, 1981; Case & Gunstone, 2002; Chin & Brown, 2000). The features that distinguish these two approaches are learning motivation and strategies (Biggs, 1993). Students with a surface approach to learning are motivated by fear of failure and tend to focus on rote learning, while students using a deep approach to learning are more likely to be motivated by intrinsic interest in learning and the topic, leading them to try to connect with prior knowledge and maximize meaning (Biggs, 1993). This process can lead to meaningful reception learning (Biggs, 1993). The differences in learning approaches could explain why students demonstrate variable learning outcomes in spite of having the same prior knowledge.

Most researches on learning approaches have focused on how to distinguish domain-general learning approaches, and researchers have tried to figure out the relationships between the learning approach and the learning outcome (Entwistle & Ramsden, 1983; Biggs, 2001). However, each discipline may involve a different epistemological process because different domain researchers experience different cognitive processes in their work. Consequently, students' surface and deep learning approaches would manifest differently according to the various disciplines (Ramsden, 1992), so it is not enough to explain students' science learning processes and outcomes by only using domain-general approaches. More recently, some research has been undertaken to explore students' learning approaches in the context of science learning in the field of science education (Chin & Brown, 2000; Chiou *et al.*, 2012; Chiou *et al.*, 2013; Lee *et al.*, 2008). For example, Lee *et al.* (2008) developed a questionnaire that provides a domain-specific approach, and they claimed that a relationship exists between the learning approach and scientific epistemology. In two studies carried out by Chiou *et al.* (2012; 2013), learning approaches were explored in terms of how they relate to the more specific scientific domains of physics and biology. One common limitation of these previous studies is that they only applied a quantitative approach to exploring relationships between conceptions of learning science and learning approaches. In other words, they did not identify educational significance in the context of the real-life science classroom.

Unlike the aforementioned research, Chin and Brown (2000) conducted a qualitative analysis of students' learning strategies when they engaged in hands-on investigations. In their paper, the distinctions between deep and surface learning approaches were classified into five categories: *generative thinking, the nature of explanations, asking questions, metacognitive activity*, and *approaches to tasks* (Figure II-6). Students who adopted a deep learning approach generated their ideas more spontaneously, focused on explaining the mechanism, asked questions to request information concerning the mechanism, and evaluated ideas or opinions through reflective thinking. They also persisted in following up on an idea with some sustained interest before moving to another one. Ultimately, Chin and Brown (2000) conducted a meaningful qualitative analysis on students' science learning approaches in an authentic context, and their classification involves domain-specific learning approaches. Hence, the features of learning approaches presented in their study can be used as a measuring tool to give more essential explanations about students' science learning.

Table II-7. Differences between deep and surface learning approach in scientific practice (Chin & Brown, 2000)

	Deep approach	Surface approach
Generative thinking	Resorted to daily life experiences, past episodes, examples, and self-generated analogies as tools to keep the thinking going	Tended to give up thinking more easily, or gave a response that did not answer the question directly or that was brief and unelaborated
Nature of explanations	Focused on the mechanism of how things worked in the physical world Tended to be more like minitheories or models which attempted to account for what was not perceptually obvious or related to personal experiences in daily life	Focused on the gross and macroscopic aspects of students' observations or were restatements of the question Did not describe causal links or a mechanism for how things happened
Asking questions	Focused on explanations and causes, predictions, or resolving discrepancies in knowledge Had a greater potential to lead to an advancement in conceptual understanding.	Referred to more basic factual or procedural information
Metacognitive activity	Displayed more cognitive appraisal and regulatory control of the learning process through ongoing reflective thinking	Engaged in less self-monitoring and self-assessment
Approach to tasks	Persistent in following up on an idea with some sustained interest before moving to another one	Give up on an idea as soon as it did not work

The study of ‘Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling’ (chapter V) aimed to identify cognitive reasoning processes during science lessons as a result of small-group modeling tasks, and the features analyzed by Chin and Brown (2000) were adapted as the framework for the study of the statements of deep learning approach. It was assume that deep learning approaches have cognitive and epistemic significance in the modeling process. In addition, modeling practice would provide the benefit of taking on the role of explaining as a *cognitive strategy* in science (Odenbaugh, 2005). When scientists construct models by organizing and articulating their ideas, they adopt prior knowledge, they reason based on comparison and metaphor, they generate visual representations, and they perform empirical or thought experiments to prove their ideas (Svoboda & Passmore, 2013). The features of scientific practice that emerged during the modeling process are similar to those features that were revealed as students engaged in the deep learning process in Chin and Brown’s study. In this sense, it was assumed that the features of a deep learning approach would be critical in order to achieve successful modeling learning.

However, Chin and Brown only focused on individual features of learning approaches, but did not identify the synergistic effects of interactions between peer students. Therefore, a study focusing both on learning approaches and cognitive collaboration in group modeling will have meaningful implications for science education, as the modeling process has social features. Modeling can be viewed as a cognitive reasoning process triggered by argumentation interactions (Böttcher & Meisert, 2011). The five features of the above deep learning approach can be elucidated as the generation of thinking, explanations about mechanism, asking questions, metacognitive thinking, and approaches to tasks. In fact, those features relate to the aims of argumentative discourse- *sense-making*, *articulating*, and *persuading*- and this kind of discourse practice may enable students to engage in cognitive collaboration in a small group setting. Therefore, a group modeling task about blood circulation was designed in this study to generate dynamic modeling practices through cognitive interaction. Cognitive collaboration and model development associated with the SD were also closely examined.

Ⅲ. Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling[1]

1. Introduction

Modeling is a dynamic process in which models are constructed and revised (Justi & van Driel, 2005). It is regarded as the central process through which scientific knowledge is developed (Justi & Gilbert, 2002). Additionally, modeling is significant in science education because it a llows students to actively construct knowledge (Ford, 2008; Greca & Moreira, 2000; Harrison & Treagust, 2000; Justi & Gilbert, 2002; Kawasaki *et al.*, 2004; Newton *et al.*, 1999). The *mental model* is defined as when students represent phenomena in their minds (Johnson-Laird, 1983). Students' mental models and their reasoning processes are revealed during the modeling process (Gobert & Buckley, 2000; Justi & van Driel, 2005). Students were able to represent difficult and complex concepts through acting, language, writing and other expressive forms. Therefore, students can test and revise their understanding of the phenomena (Chittleborough *et*

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[1] The study in chapter III was published as follows: Lee, S., Kim, C. J., Choe, S. U., Yoo, J., Park, H., Kang, E., & Kim, H. B. (2012). Exploring the patterns of group model development about blood flow in the heart and reasoning process by small group interaction. *Journal of the Korean Association for Research in Science Education,* 32(5), 805-822.

al., 2005).

The effects of model-based learning are enhanced when students construct group models by participating in the group modeling process. This is due to the fact that individual students are limited in the construction and revision of their own models. Instead, group modeling requires students to generate, revise, and develop a collaborative model by interacting with their group members. Group modeling is based on the sociocultural perspective, in which verbal interaction is the essential factor in knowledge construction in science classrooms (Lemke, 2001; Moll & Whitmore, 1993; Sfard & Kieran, 2001; Vygotsky, 1978).

In the sociocultural perspective, students learn by participating in a shared activity through peer discussion (Lave & Wenger, 1991). In other words, students participate in learning and internalizing new information by interacting with each other until they acquire the information as their own. Several researchers have concluded that group learning benefits students by giving them the chance to be a leader during the formation of scientific knowledge. This leadership experience has a positive effect on learning during interaction among students (Bennett *et al.*, 2010; Cohen, 1994; Linn & Burbules, 1993; Nastasi & Clement, 1991; Qin *et al*., 1995; Slavin, 1990). However, all group activities provide students with the opportunity to construct collaborative knowledge; therefore, this specially designed instruction should be suggested to students for active peer discussion (Hogan, 1999). Some researchers believe that analogy could facilitate students' spontaneous reasoning (Coll *et al*., 2005; Duit, 1991). Instructional design that uses analogy is conducive to students' facility with verbal interaction in group modeling on one-way blood flow in the heart.

Another benefit of group modeling is that it allows students to reason as a form of argumentation (Sampson & Clark, 2009). Argumentation is a communicative activity that scientists engage in when they dispute scientific issues and build scientific theories (Kuhn, 1962). In science classrooms, students can also experience the argumentative activity by judging the suitability of models and justifying their explanatory models to others. Through argumentation, students evaluate and modify a given model by adopting a more suitable model (Böttcher & Meisert, 2010). Students then must argue for the validity of their own models. As a result, the explanatory model can be enhanced through the logical reasoning process (Berland & Reiser, 2009).

Though many studies related to modeling have been conducted in Korea recently, most consisted of studying individual mental models or conceptual change by exploring the individual mental model (Jeong, 2007; Kim & Kim, 2007; Oh & Kim, 2006; Park & Lee, 2008). Other researchers have also emphasized the importance of scientific communication (Cho *et al*., 2008; Kang *et al*., 2002; Kim *et al*., 2005; Kim & Song, 2004; Lee *et al*., 2010; Lee & Kim, 2011; Lee & Lim, 2010). There are, however, no current qualitative attempts to explore the construction of the scientific model through group modeling, or the reasoning process in group modeling.

This study explored gifted middle school students' process of constructing explanatory models on one-way blood flow in the heart by participating in group activities such as a siphon pump analogy activity and a dissection of pigs' hearts. Concepts such as natural selection, diffusion, heredity, and blood circulation are invisible and hard to experience. In particular, the circulatory system is difficult for students to understand. This is because the exploration of blood circulation involves a wide range of scales that encompass both the visible (heart, veins, and arteries) and the invisible (blood cells, oxygen, and carbon dioxide in a capillary) (Buckley, 2000; Kim & Kim, 2007). Therefore, this study used the siphon pump as an instructional material for facilitating verbal interaction because it helped students to visualize both microscopic and abstract concepts (Duit, 1991). The siphon pump could help students construct the explanatory model of blood circulation and could also be a useful tool for identifying the change of models and reasoning process. The research questions were as follows:

1) What are the patterns of model developments in group modeling?
2) Which factors cause differences in reasoning among several group models?

2. Method

2.1. Participants

14 students in the eighth grade at the K gifted science education center in Seoul participated in this study (Table III-1). They attended a middle school that belonged to the same administration/education office and were selected for the K gifted science education center through a meticulous method that reflected teachers' recommendations and in-depth oral interviews. From their entrance into the gifted science education center in 2010, they were enrolled in a specialized program for highly talented students that included summer school, summer camp, and regular autumn lessons (twice a week) in the same classroom for 6 months. Their academic achievements were within the top 10% in their school and they showed greater interest in science than in any other subject. These students were arranged in groups of three or four (four groups). Group members were decided based on their relation of friends.

Table III-1. Description of boys and girls who participated in each group (n=14)

Group	Gender		Total
	Boy	Girl	
A	0	3	3
B	3	0	3
C	2	2	4
D	4	0	4
Total	9	5	14

2.2. Context

The instructional unit consisted of four steps that took three hours (Figure III-1). In step one, students reviewed their prior knowledge about the heart's structure and circulatory system by looking at a diagram of the heart and discussing the locations and roles of each component. Next, a siphon pump was provided as a pedagogical analogy model since its structure and function is similar to the heart. Students worked in groups to manipulate the pump and then they constructed models to explain how one-way water flow works in the siphon pump.

In addition to its function as a model, the siphon pump maintained students' interest in the project and inspired their interaction. Students modeled one-way water flow in the siphon pump by discussing the answers to questions provided by the teacher. This step two demonstrated modeling phase one.

In step three, students worked in groups to dissect and observe the structure of pigs' hearts. Though the siphon pump served a positive role as a pedagogical analogy model, it was not a perfect analog (or model) of the human heart. Therefore, students used the pig hearts to identify differences between the analogy and the real object. Finally, through group discussion, students presented and revised their group models of one-way blood flow in the heart. This step four demonstrated the second modeling phase.

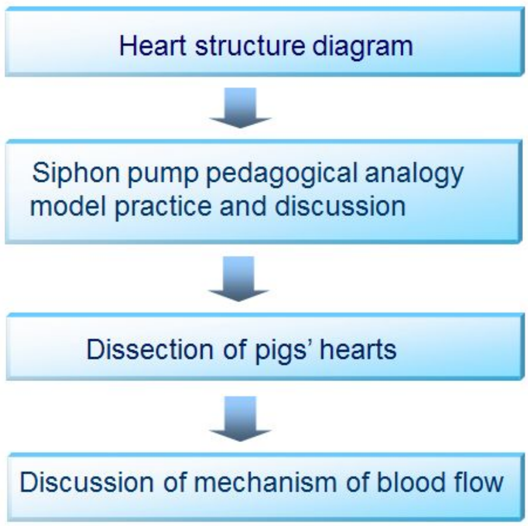


Figure III-1. Process of the instruction

2.3. Data Collection and Analysis

These lessons on blood circulation were videotaped and included audio. From this recording, the discussion between the teacher and students was transcribed; people's gestures during communication were also recorded. The participants responded to a survey after the lessons to gauge students' perceptions of small-group activities and of the roles they played in their groups, and also determine students' levels of prior knowledge regarding blood flow in the heart. The model development process described in Clement was modified to analyze students' interactions and their processes for developing their own models (Clement 2008, pp. 11-22). The process of development was examined by analyzing the statements of both the student leader and non-leading students. Figure III-2 shows the framework for the process of model development regarding the first modeling phase of group one. The statements of the student leaders, the teacher, and the non-leading students are presented in three different sections. As can be seen, square boxes include students' statements, which are represented with directional lines/arrows to depict the target of a given communication. Some omitted parts and meaningful behaviors are depicted in parentheses by the researchers. The rounded squares in the middle part represent the models and are placed in order of development (i.e., M0, M1, M2, M3, and M4). If there are two more competing models, these models are placed parallel to each other (as with M2 and M3). If the model is abandoned, “X” is marked in the round square. If the explanatory model is unclear in students’ statements, researchers describe the content of the models based on the context of the discourse.

The small squares show the order of the utterances. For example, St2-8, in the small square, represents the eighth utterance of Student 2, and Tr-4 represents the fourth statement of the teacher. Moreover, the thin arrows represent the students’ statements and inferring models, while the thick arrows indicate the process of model development. Use of this framework greatly facilitated examination of the generation, evaluation, and modification process of the models and the statements, and provided considerable information concerning the degree to which certain students contributed to the development of the model.

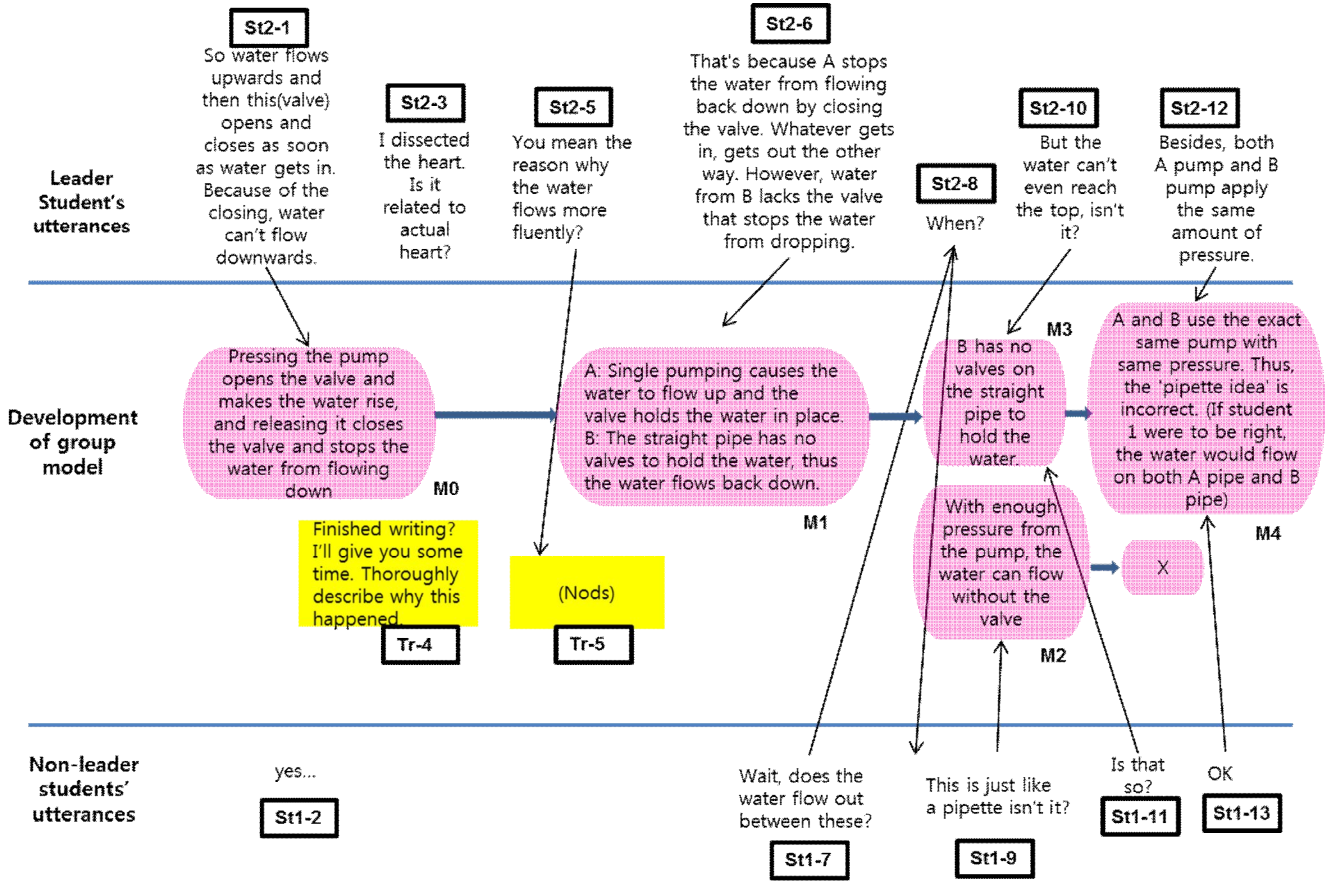


Figure III-2. Framework for model development - Modeling phase 1 of Group A. Group model = M0, M1, M2, M3, M4; Student ID - Order of utterance = St2-1, St1-2, St2-3 …St1-13; Teacher - Order of utterance = Tr-4, Tr-5

The target models were set so that the suitability of models that students constructed collaboratively could be judged. Figures III-3 and III-4 visualize the target model using the method introduced in the study of Buckley and Boulter (Buckley & Boulter, 1996, p. 128). The structure of the objects is placed in the boxes; the explanations above the arrows represent the actions, and the bigger square boxes show the mechanism. The target model of modeling phase 1 was intended to explain the direction of the water flow in the siphon pump, which is controlled by the opening and closing of the valves in the pipe and affected by the contraction and relaxation of the pump (Figure III-3). The target model of modeling phase 2 was intended to explain one-way blood flow in the heart with heart pumping using the experience in the modeling phase 1 (Figure III-4). The qualities of group models were evaluated with three elements of the target model.

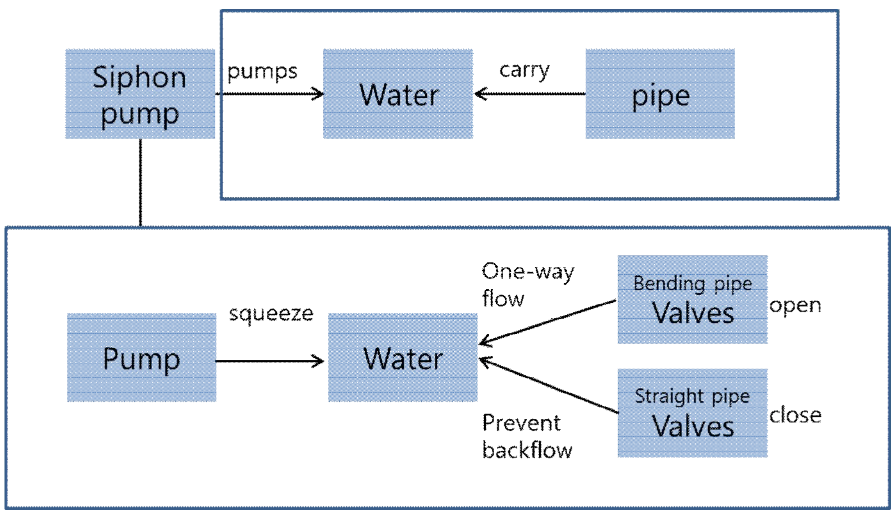


Figure III-3. Target model of the modeling phase 1

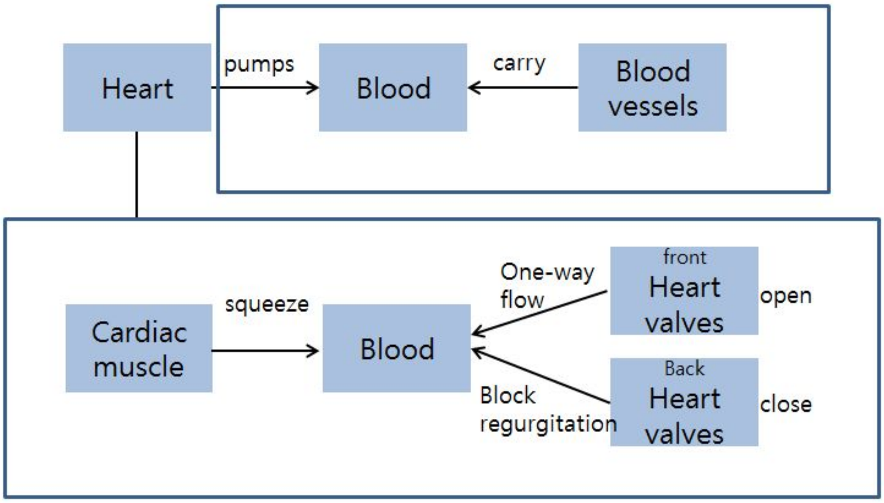
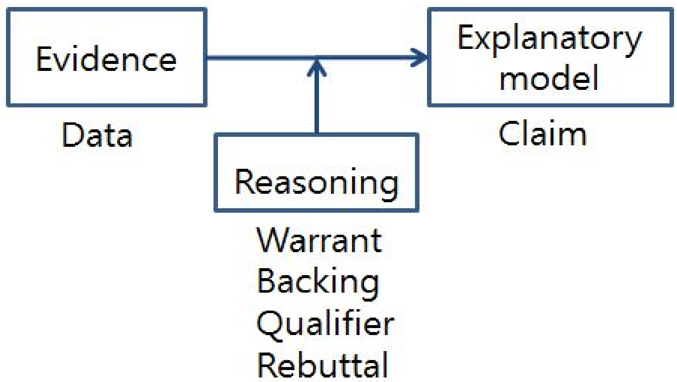


Figure III-4. Target model of the modeling phase 2

The framework for scientific argumentation used by Sampson and Clark (2009) has been adopted to develop a framework related to students' reasoning processes for this study. Sampson and Clark developed this framework for analyzing the qualities of argumentation, which conceptualizes scientific argumentation as having three interrelated elements (an explanation, evidence, and reasoning) by using a much earlier framework developed by Toulmin (1958). In this framework, *explanation* is the answer to the research question; *evidence* refers to measurements or observations that support the validity or legitimacy of the explanation; *reasoning* is the process of justifying how the evidence supports the explanation and why it should be considered supportive. Figure III-5 shows the correspondence between the framework for scientific argumentation developed by Sampson and Clark (2009) and used in the present study and the argumentation elements of Toulmin (1958). After developing the framework, the author and the other person who was a PhD student independently conducted data coding. If there were differences in data coding, it was tried to achieve a consensus through discussion.



Data: Statements that are used evidence to support the claim
Claim: Assertions about what exists or values that people hold
Warrant: Statements that explain the relationship of the data to the claim
Backing: Underlying assumptions that are often not made explicit
Qualifier: Special conditions under which the claim holds true
Rebuttal: Statements that contradict either the data, warrant, backing or qualifier of an argument.

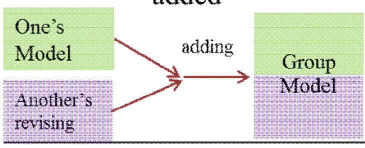
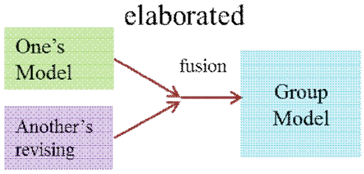
Figure III-5. Framework for reasoning process of modeling

3. Results and Discussions

3.1. The Patterns of Group Model Development

From the sociocultural perspective based on the theory of Vygotsky (1978), learning occurs when the knowledge formed by interaction between teachers and students, or between students and students, is internalized. Lave and Wenger (1991) insisted that learning is viewed as the participation of community members in specific activities, contexts, or cultures. After analyzing students' group modeling process based on this perspective, it was found that some factors—model revising, model provider, and leader style—influence interaction among group members. The processes of model development influenced by social interaction were categorized by three patterns—*unchanged*, *added*, and *elaborated* (Table III-2). When students participated actively in the process of model development, group models became close to the target model or initial models became persuasive explanatory models due to students' attempts to justify claims during the reasoning process.

Table III-2. Patterns of group model development related to the interaction characteristics

Patterns of Model change	Model revision	Model suggestion	Leader style	Example
unchanged 	Not happening	Only leader	Alienating	Group B-2
added 	Revised by someone's critique & evaluation	Not only leader	Persuasive	Group C-1
elaborated 	Revised by someone's critique & evaluation	Not only leader	Persuasive	Group A-1 Group B-1 Group C-2 Group D-1 Group D-2
	Self-revised		Inclusive	Group C-1

The patterns of group model development were different according to the characteristics of interaction. First of all, critical revision of models was the primary factor that led to the development of certain interactional characteristics. During revision or reconstruction of their models, students judged the suitability of the models by checking whether the phenomena were explained correctly (Gobert & Buckley, 2000). *Critical revision* was defined as “students modifying their own or others’ models by considering their existing models”. If the models could not explain the phenomena scientifically, they were rejected and elaborated on by the addition of other models or by being reorganized (Hafner & Stewart, 1995).

Students who suggested the models continued to be important in deciding the patterns of model development. In most of the cases of group modeling, the initial modelers were leaders. Students who were not leaders, however, sometimes suggested models for developing group models, and students actively interacted with each other when providing explanatory models or suggesting revisions to such models in group interactions. After suggesting the initial models, several students participated in providing additive models. These models, then, were compared and evaluated implicitly or explicitly and became consensus models.

Another main factor in the process of model development was the role of the group leaders, who influenced how and to what extent other group members participated in the interaction. Richmond and Stirly (1996) identified leadership styles by focusing on the social traits of a potential leader (such as the "alienating leader", the "persuasive leader", and the "inclusive leader"). Alienating leaders try to prove that they are right and demonstrate intellectual superiority; persuasive leaders usually are able to convince others to follow their lead; inclusive leaders suggest scientifically correct arguments based on synthesis and try to distribute work (and credit for the work) among the group members. Leaders in each group were identified based on the findings of Bianchini (1997) that students who actively participated in group discourse contributed to group learning and had a higher position than other students within a group. After the leaders were identified, their leadership styles were analyzed using the findings of Richmond and Stirly (1996).

3.1.1. The unchanged pattern

The *unchanged* pattern of model development was found in cases in which the initial model became the final group model without being revised or developed. In these types of groups, the leader suggested the model but others just listened or agreed with the leader's opinion; in other words, there was no critical revision of the model. In this pattern of interaction, the leaders had an alienating style and did not consider others' points of view, but instead emphasized their own models. Accordingly, the social interaction for model development did not occurred.

Figure III-6 shows this pattern in modeling phase 2 of Group B. Student 3, who had an alienating style of leadership, suggested that his model was close to the target model of one-way blood flow in the heart (St3-1). Student 3 blocked the expression of other opinions by saying: "Have we finished talking?" (St1-3). Rather than reject this ending of the discussion, or complaining, the other students agreed with his model as the final group model provisionally and ended the modeling process (St4-4). Student 3 used the term "squeezing" for expressing the meaning of contracting. This word was not scientifically correct for explaining the mechanism of one-way blood flow in the heart. However, critical revision did not take place, so this remained incorrect. Finally, this everyday word was not corrected as the scientific term, and the initial model was not elaborated by adding the explanation of mechanism in the case of the heart's relaxing.

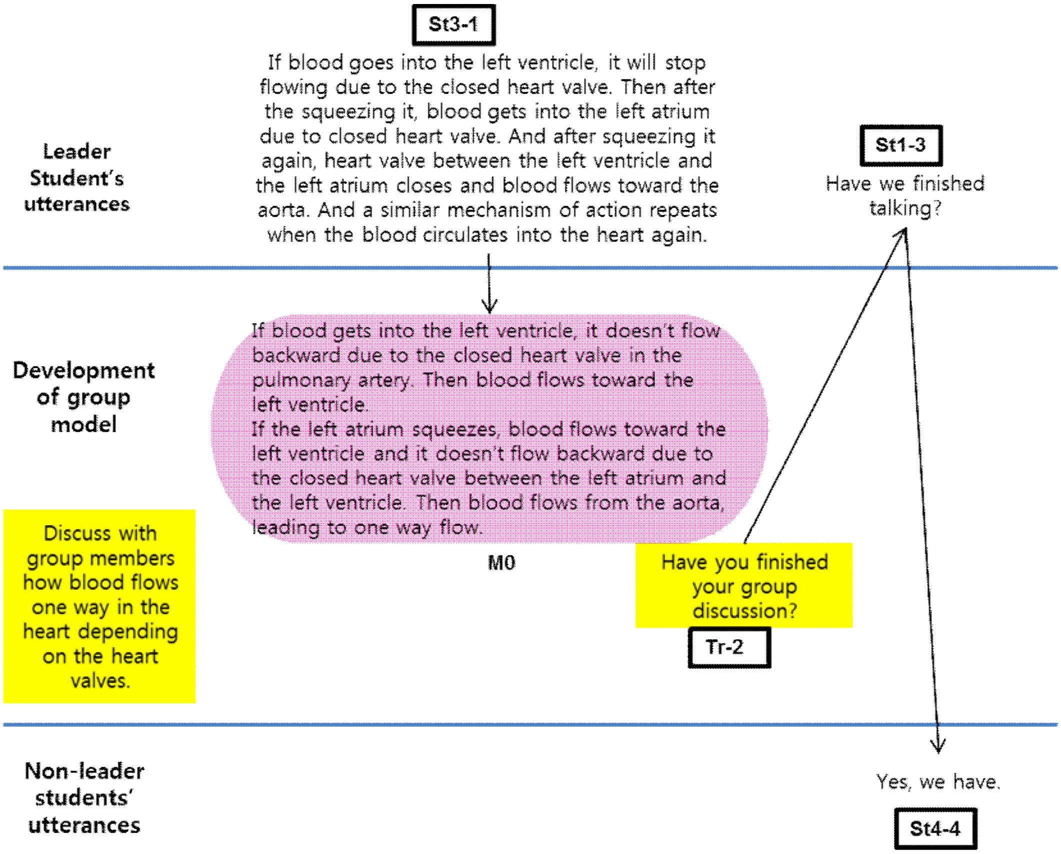


Figure III-6. Discourse of the *unchanged* pattern – Modeling phase 2 of Group B. Group model = M0; Student ID - Order of utterance = St3-1, St1-3, St4-4; Teacher - Order of utterance = Tr-2

3.1.2. The added pattern

The *added* pattern of model development was found when both the student leaders and other group members suggested additive model for developing the group model. More than one student participated in group interaction by monitoring the initial model, then adding his or her own model for development of an overall group model. Accordingly, the group model developed in a way that was close to the target model. These student leaders adopted a persuasive style and tried to argue on behalf of their own model. For example, they monitored their own or others' models, then added models which supplemented the previous model with missing elements, bringing the model closer to the target model.

Figure III-7 shows this pattern, which was found in the group modeling phase 1 of Group C. Student 3 generated the initial model M0 and M1 by referring the explanation the relation between the water flow and the movement of the valves (St3-2 and St3-4). Student 4 monitored Student 3's model critically and provided the additive model M2 that explained the relation between the contraction of the pump and the movement of the valves (St4-7). M2 contained the explanation of the opening and closing of the valves when the pump was contracted. Student 3 also monitored this model critically and added M3, which accounted for the water flow with release of the pump (St3-9). The group's model closely adhered to the target model because the model of Student 3 (M3) complemented M2. Student 4 did not impose his own model but monitored Student 3's model critically and added some missing points. As a result, the final group model developed into the target model through the participation of several students in the cognitive chain reaction of critical revision.

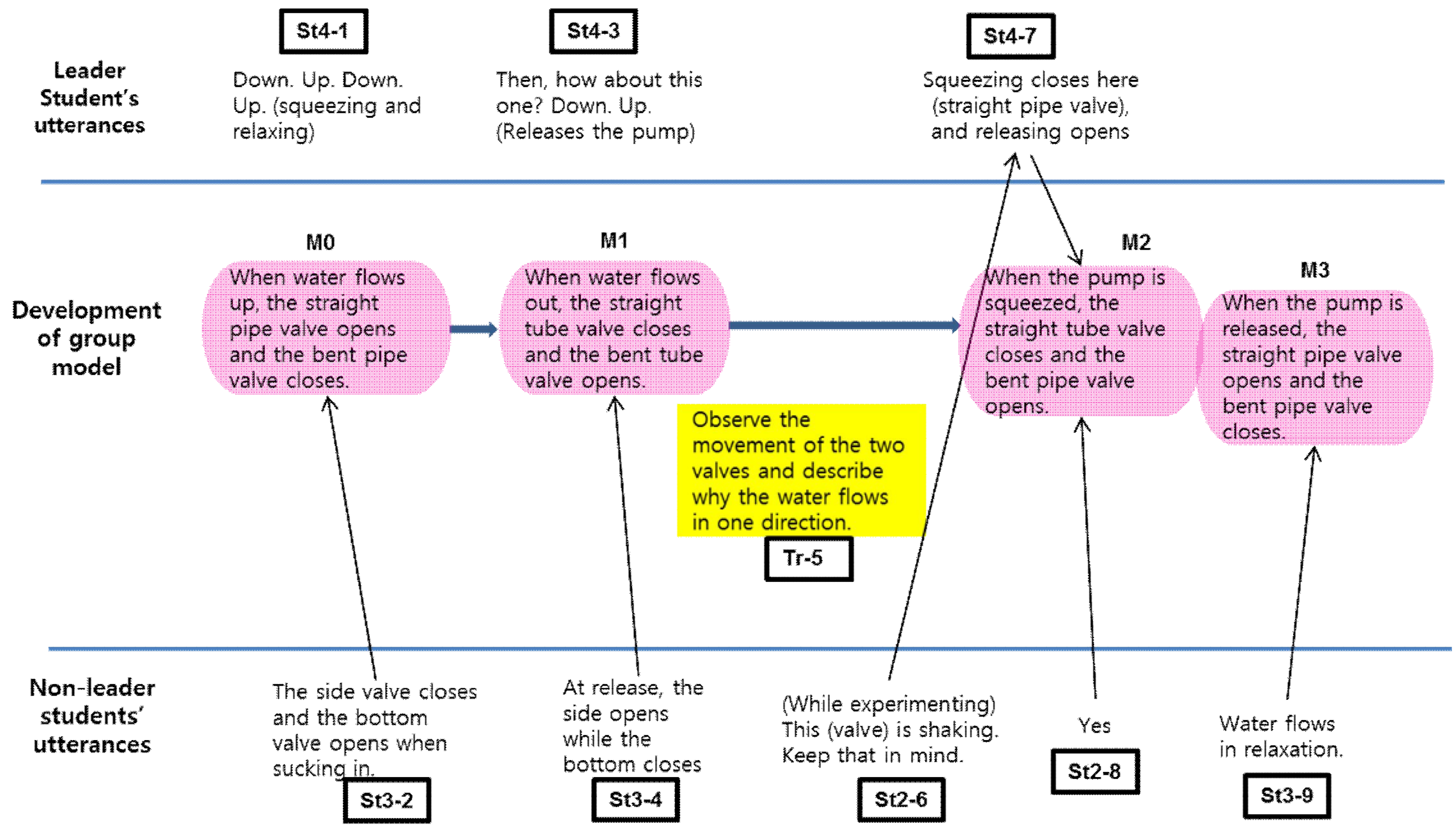


Figure III-7. Discourse of the *added* pattern – Modeling phase 1 of Group C. Group model = M0, M1, M2, M3; Student ID - Order of utterance = St4-1, St3-2, St4-3….,St3-9; Teacher - Order of utterance = Tr-5

3.1.3. The elaborated pattern

The *elaborated* pattern of model development was found when additive models were fused with the initial model for development of the group model. The models were monitored and modified by modelers' self-reflection or other students' critiques. Group interaction occurred actively in this pattern because several students participated in group modeling and the student leaders had either persuasive or inclusive styles. If students had difficulty in critically revising the models, the teacher intervened in the group modeling process for the purpose of assisting this evaluation. Participation of group members contributed to generating and developing the group models so that the elaborated form of model development could be regarded as collaborative modeling. This pattern was found most frequently in this study.

Figure III-8 shows this pattern found in the group modeling phase 2 of Group A. Student 2 generated M0 and asked a question that served the role of requesting Student 1's participation for collaborative modeling (St2-1). Student 2 generated from M0 to M4 with Student 1 considering the blood pathway. Student 1 provided M3, referencing not only the one-way blood flow in the heart but also the systemic circulation (St1-4). Though M3 did not directly influence the construction of the final model M6, it served a role of scaffolding for relating the blood flow with the heart valves and stimulated Student 2's self-reflection. Student 2 reflected and monitored the existed models critically by asking a question and providing an answer. Student 2 was able to build M5 by considering the relationship between the one-way blood flow and the heart valves. After a series of interactions characterized by critical revision by self-reflection (St2-12, St2-13, and St2-14), Student 2 constructed the final model M6 that explained the direction of the blood flow in the heart, which is controlled by the opening and closing of the heart valves and affected by the contraction and relaxation of the heart. Student 2 was the inclusive leader that not argued persuasively on behalf of her models but also encouraged the participation of others. This process resulted in collaborative modeling with other group members.

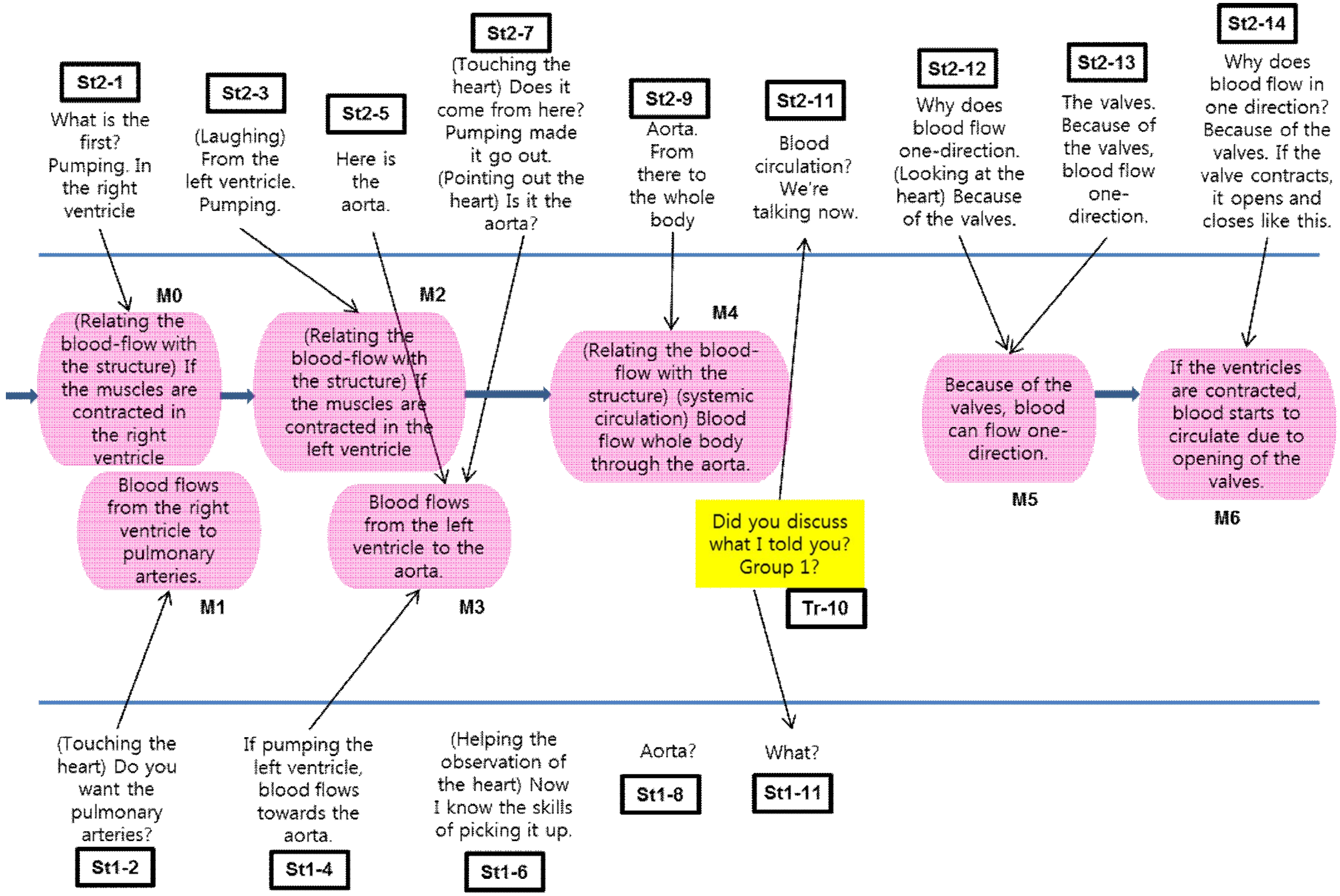


Figure III-8. Discourse of the *elaborated* pattern – Modeling phase 2 of Group A. Group model = M0, M1, M2, M3,…M6; Student ID - Order of utterance = St2-1, St1-2, St2-3….,St2-14; Teacher - Order of utterance = Tr-10

Figure III-9 also shows this pattern, which is found in phase 1 of modeling for Group D. In this case, the teacher and students monitored the model critically. Student 4 generated M0, in which the valves prevented water backflow (St4-3). Student 3 revised Student 2's model (M0) by using the term "the valves" instead of "the heart valves" and adding the explanation of the relation between the contraction and relaxation of the pump and the opening and closing of the valves in terms of the function of the pump (st3-4, M1). As the teacher asked students to explain the mechanism of the one-way blood flow in the heart (Tr-6 and Tr-8), student 3 volunteered to present M2 that was close to the target model (St3-9). However, the contracting and the relaxing in M2 were contrary to the target model. The teacher asked an evaluative question about M2 (Tr-10) to Student 3, enabling the student to modify his model appropriately (St3-11). Though students constructed the final model through collaborative modeling by group discussion, their models did not get to the target model. The teacher served the critical role of developing the model for students to monitor their own model critically by themselves. In other words, the teacher intervened actively in the group modeling process for revision of the group's model. In the absence of this guidance, the students would have learned the wrong target concepts concerning inquiry in the science classroom (Crawford, 2000).

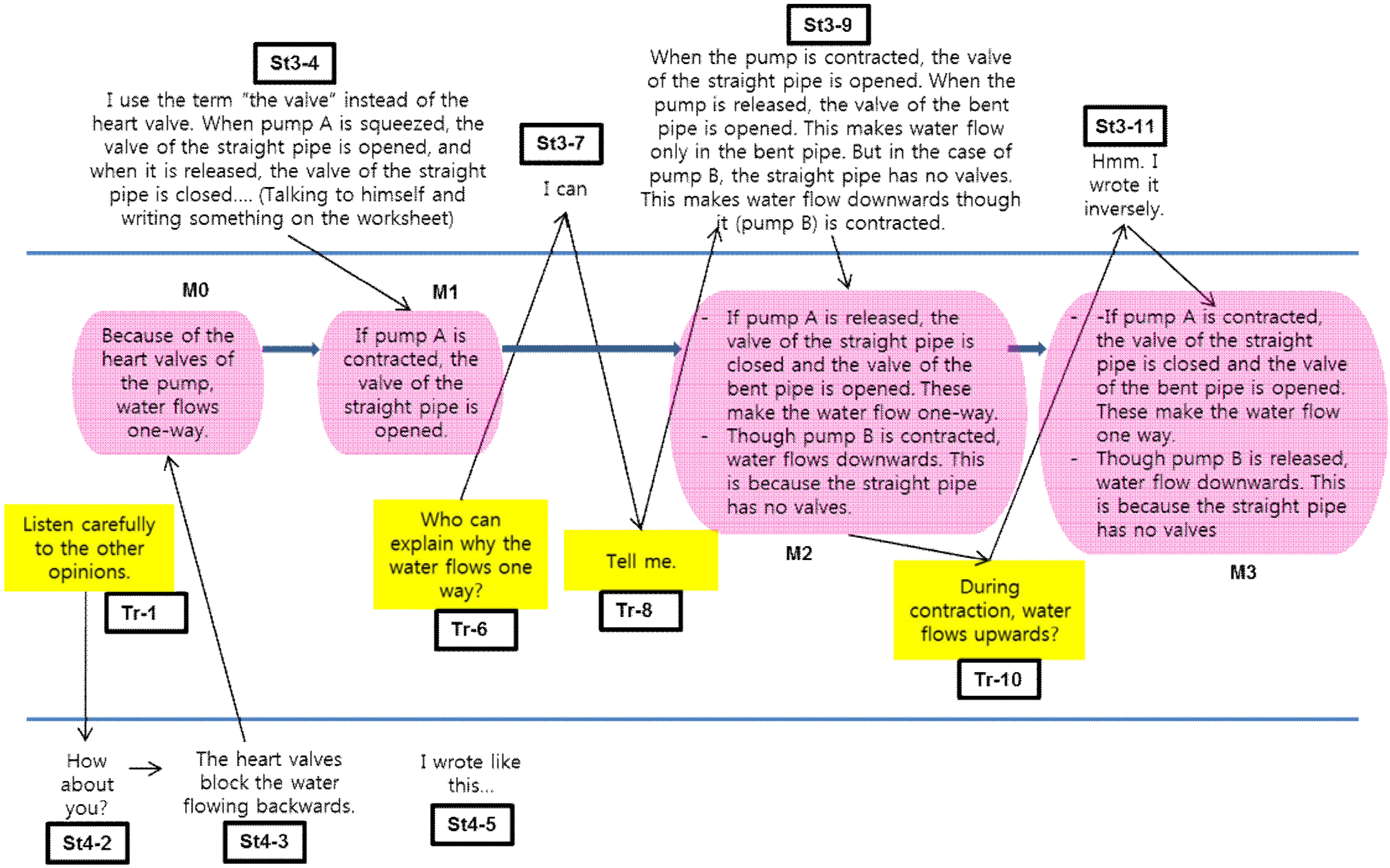


Figure III-9. Discourse of the *elaborated* pattern – Modeling phase 1 of Group D. Group model = M0, M1, M2, M3; Student ID - Order of utterance = St4-2, St4-3, St3-4….,St3-11; Teacher - Order of utterance = Tr-1, Tr-6, Tr-8, Tr-10

In summary, students in groups could construct models collaboratively both on an individual plane and through interaction. In the unchanged pattern of model development (i.e., a model that was not critically revised), an individual model became the group model, and learning was not collaborative but individual. However, in the added and elaborated pattern of model development, several students participated in the process of critical revision and generation of the model, and the group models were constructed closely to the target model in social plane. Through critical revision, several students either suggested additions to the initial model or elaborated on models in such a way that their models were fused with the initial model. Through this process, the initial model closely approached the target model both through critiques and through self-reflection on the part of the student leader who proposed the initial model. The way in which students justified their models (that is, their reasoning processes) will be discussed in the next section.

3.2. Factors Influencing Reasoning Process in Group Modeling

Modelers who provided the initial models tried to justify these models when cognitive conflict within a group occurred. This conflict arose during critical revision that had the intent of criticizing, evaluating, and revising of the initial model. Students questioned others' viewpoints and justified models in terms of the form of the argument. These processes were similar to the discourse that takes place in the scientific community (Ritchie, 2001). Students reasoned on behalf of their models by expressing the warrant, backing, and rebuttal that are the elements of argumentation. Accordingly, students had insight into the suitability of the initial models and monitored the models critically in order to improve their quality (Böttcher & Meisert, 2010).

Sampson and Clark (2008) explained the reasoning process, which constructs the explanatory model based on the evidence with the argumentation elements identified by Toulmin (1958). They regarded *reasoning* as the justification of the explanatory model— how the evidence supported the explanation and why the evidence was important. Modeling processes were analyzed with the framework for the reasoning process of modeling (Figure III-5). Reasoning that had the diverse elements of argumentation was well-expressed in the elaborated pattern of model development (see Table III-3). Students reasoned with the diverse elements of argumentation when engaged in active discussions to justify their own models. Therefore, reasoning that had the diverse elements of argumentation was regarded as demonstrating a high level of reasoning. Students usually reconstructed the initial models based on the evidence if their claims were challenged by others during group discussion. The evidence was the background knowledge or experience that was obtained from the siphon pump analogy model activity or from the dissection of the pigs' hearts. Students used the evidence from these activities to provide reasoning that gave validity to the models they developed.

Most group models got close to the target model with the exception of the models from modeling phase 2 of Group B and modeling phase 2 of Group C (see Table III-3). In modeling phase 2 of Group B, the incorrect model put forth by the alienating leader became the final group model without critical revision; in modeling phase 2 of Group C, there was critical revision but the modeler justified own model with teleological reasoning that the blood flows toward the pulmonary arteries in order to supplement the blood with oxygen. The reasoning was not validated scientifically, so the final model did not get to the target model.

The reasoning processes of each group were examined with the existence of the argumentation element. Even though students had the same target model and the same activities, their reasoning levels were different. Most modeling processes have low-level reasoning that contained only the warrant among the argumentation elements. However, modeling phase 1 of both Group A and Group B contained high-level reasoning that included diverse argumentation elements. The factors influencing high-level reasoning and the modeling process will be discussed in the next section.

Table III-3. Differences of reasoning process in group modeling

		Group A		Group B		Group C		Group D	
		P1	P2	P1	P2	P1	P2	P1	P2
Evidence source	Background knowledge	o	o	o	o	o	o		o
	Siphon pump and dissection of pig's heart	o	o	o		o		o	o
Reasoning	Warrant	o	o	o	o	o	o	o	o
	Backing	o		o					
	Qualifier								
	Rebuttal	o		o					
Close to the target model		o	o	o		o		o	o
Patterns of model change		el	el	el	un	ad	el	el	el

Abbreviation P1 : group modeling phase 1, P2 : group modeling phase 2
un : unchanged , ad : added , el : elaborated

3.2.1. The differences of reasoning process according to the task features of modeling activities

The reasoning processes in group modeling were analyzed with the argumentation elements of Toulmin (1958). High-level reasoning processes in which diverse elements of argumentation existed were found in modeling phase 1 for both Group A and Group B (Table III-3). The factors influencing this process were the task features of the modeling activities (Table III-4).

In modeling phase 1, students constructed their models by manipulating the siphon as a manner of engaging in scientific inquiry. The siphon was the pedagogical analogy model. As a simulation of the heart's pumping mechanism, the structures of the siphon pump and the heart are similar structures, and the mechanisms of water flow and blood flow are similar. Thus, this activity helped students sustain their interest and have a better understanding of the concept. The siphon served as a simplified representation of phenomena or concepts—as an intermediate between the target concepts and the students' explanatory models (Coll *et al*, 2005). The siphon pump represented the part of the structure and the function of the heart and the 3-D analogy model that enabled students to manipulate it easily and observe the phenomena. This encouraged students to reason spontaneously by putting forth their own opinions and interacting with each other verbally. Accordingly, the most explanatory group models matched the target model and could explain the mechanism of the water flow with the relationship between the opening and closing of the valves and the contraction and relaxation of the pump. To sum up, students could explain the dynamic water-flow by considering the structure of the pump.

In modeling phase 2, students engaged in a more complex modeling activity after dissecting and observing pigs' hearts. These hearts had a complex structure consisting of two atriums, two ventricles, four vessels, and more than two valves. Students could observe the complex structure but not the blood flow. It was impossible for students to manipulate the hearts' function. Therefore, students constructed the group models through connecting the experience of the dissection of the hearts with the experience of modeling phase 1 and other background knowledge; this can be called indirect reasoning. As a result, some group models did not explain the mechanism with consideration of the relationship between the blood flow and the opening and closing of the heart valves.

Furthermore, some students already knew the content of the target model in group modeling phase 2 because of what they had learned in school. These students revealed their background knowledge in the beginning of the modeling process. Accordingly, students who did not have this foreknowledge could not rebut it or construct counterarguments. This finding supported the results of Millar (1998), which pointed out that it was difficult for students to have critical and active discussions in the context of existing scientific knowledge.

Table III-4. Differences between modeling phase 1 and 2

	Modeling phase 1	Modeling phase 2
Inquiry activity properties	Siphon pump manipulating − Simple structure − Possible to manipulate − Direct observation of "structure of pump" − Direct observation of "water flow"	Dissection of pigs' hearts − Complex structure − Impossible to manipulate − Direct observation of "structure of heart" − Direct observation of "blood flow" was impossible
Reasoning properties	Spontaneous reasoning depending on previous direct observation	Reasoning depending on siphon pump activity and scientific knowledge
Explanatory model properties	Most explanatory models were consistent with the target model. − Explained the mechanism with the relationship among releasing and squeezing of pump, opening and closing of valves, and water flow	Some of the explanatory models did not meet the target model. − Although they described the pathway of blood flow, they didn't explain the mechanism of opening and closing of heart valves.

3.2.2. The reasoning processes influenced on cognitive conflict among group members

Among the elements of argumentation identified by Toulmin (1958), rebuttals were a frequent feature of discourses containing cognitive conflict among group members. Rebuttals consisted of statements that contradicted the data, warrant, backing, or qualifier of an argument (Simon *et al.*, 2006). Modelers who suggested the initial model were the persuasive leaders and contributed to reveal the diverse elements of argumentation (Berland & Reiser, 2009). Modelers participated in argumentation by refuting the rebuttals and justifying the initial models. Accordingly, enlarging of the rationale for the models and critical revision allowed the group models to develop so that they more closely matched the target model.

1) The elaborated reasoning by justification

The cognitive conflicts were found in the reasoning process with rebuttals. Lee and Kim (2011) insisted that cognitive conflict in group discussion is the main factor that facilitates the development of argumentation. It was also the critical factor for enlarging the rationale of the model because it induced the modelers to justify their initial models. The diverse elements of argumentation were revealed during the justification process.

Figure III-10 shows this process as found during modeling phase 1 of Group A. Student 2 generated M0, which was similar to the target model, based on her experience of manipulating the siphon pump (Line 2). Student 1 provided a different model in which the mechanism of the water flow was similar to that of a dropper as a form of the question (Line 8). M1 was the counter model to M0 and also served the role of the rebuttal that induced cognitive conflict within their group. Student 2 countered with evidence that suggested it is impossible to explain the phenomena only with the pressure within the pump because pumps A and B were the same pump with the same pressure (Line 9 and 11). These statements were the backing of M0 among the argumentation elements. Furthermore, Student 2 explained the storage ability of the water in the pump in connection with both the existence of the valves and the valves' opening and closing (Line 13). This statement enlarged the rationale for M0. In summary, the modeler who generated the initial model defended the model with metacognition by refuting the counter model and enlarging the rationale.

	Speaker	Statement	Evidence	Reasoning process	Explanatory model
1	Tr	Pump A was working but pump B wasn't. Observe the inner structure of both A and B. Before doing that, manipulate these pumps to find out the differences in the structure between them.			
2	St2	Oh. These two pumps are different. In this, there is a valves like heart valves. In that pump, there's no valves. Because there're no valves, water flows up and down. (pointing out the inside)			
3	St1	Oh..this (pointing out the valves in the pipe) moves.			
		(omission)			
4	St2	If you squeeze the pump			
		(omission)			
5	St2	That's because A stops the water from flowing back down by closing the valve. Whatever gets in, gets out the other way. However, water from B lacks the valve to stop the water from dropping.			
6	St1	Wait, does the water flow out between these?			
7	St2	When?			
8	St1	This is just like a dropper isn't it?			
9	St2	But the water can't even reach the top is it not?			
10	St1	Is that so?			
11	St2	Besides, both A pump and B pump apply same amount of pressure			
12	St1	OK (nod)			
13	St2	So for example, if this (water) flows upwards, in A, half the water get the other way. But in B, all the water get the other way.			
14		(Students fill out worksheets individually.)			
15	St1	Are there two valves in the pump?			
16	St2	Pardon?			
17	St1	Are there two valves in the pump?			
18	St2	Yes. There are two valves in A, and one valve in B.			

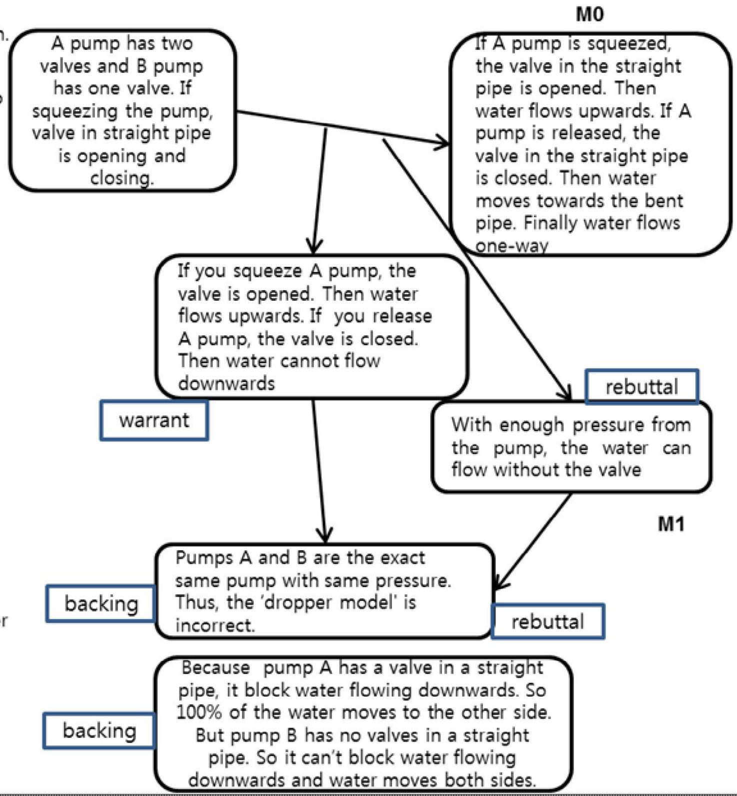


Figure III-10. Reasoning process in modeling phase 1 of Group A

2) The modification of the explanatory model

The cognitive conflict within a group influenced not only the enlarging of the model's rationale, but also the modifications of the models in order to bring them closer to the target models. Figure III-11 shows modeling phase 1 of Group B. Student 1 generated the initial model M0, in which Pump A enabled the water to flow through the bent pipe because it had two valves (Line 2). Student 2 expressed the cognitive conflict within the group by saying that Pump B would enable the water to move in the same way that Pump A did (Line 5). Student 1 provided the rebuttal and M1, which accounted for water storage within the head of the pump, in order to rebut student 2's rebuttal (Line 7 and 9). Further, Student 3 stimulated Student 1's metacognitive thinking by asking about whether they should talk about the heart valves (Line 10). As a result, as a group the students modified M1 and generated M2, which was closer to the target model (Line 11).

In this modeling process, the question posed by Student 1 made students' understanding clearer and increased discussion around resolving things that were still in doubt. Accordingly, this process stimulated divergent thinking that guided the cognitive process (Chin & Osborne, 2008). The cognitive conflict within a group, and the participation of many students in terms of raising questions, influenced the modeler as the initial modeler was developed into the target model. The initial modeler argued against the rebuttals after recognizing the correct explanatory model more clearly after further reflection

	Speaker	Statement
1	Tr	Pump A was working but pump B wasn't. Observe the inner structure both A and B. Before doing that, manipulate these pumps and find out the different structure between them.
2	St1	A pump has two valves and B pump has one valve.
3	Tr	Observe the direction of water flow and whether it is working or not.
4	St1	Ok. Out and in (Observing the structure of the pump while squeezing and releasing the pump)
5	St2	Does B pump enable water to move like A pump?
6	St3	No, B pump is weaker.
7	St1	A pump is better. Because you pumped quickly, you can think like that
8	St2	Ok...
		(omission)
9	St1	If the water gets in the pump, it will get out of the pump. But small amounts of water get into B pump.
10	St3	It's better to talk about the heart valves.
11	St1	Yes. If water got into A pump, valve became closing. Then water moved to the other side. But B pump didn't enable water to store in the pump. Squeeze and release again and again. Small amounts of water stored in the head of the pump.
		(omission)
12	St3	When this (the pump) is squeezed, the water flows upwards and get in to the pump. Then the valve of straight pipe is opened. Ah There is the valve

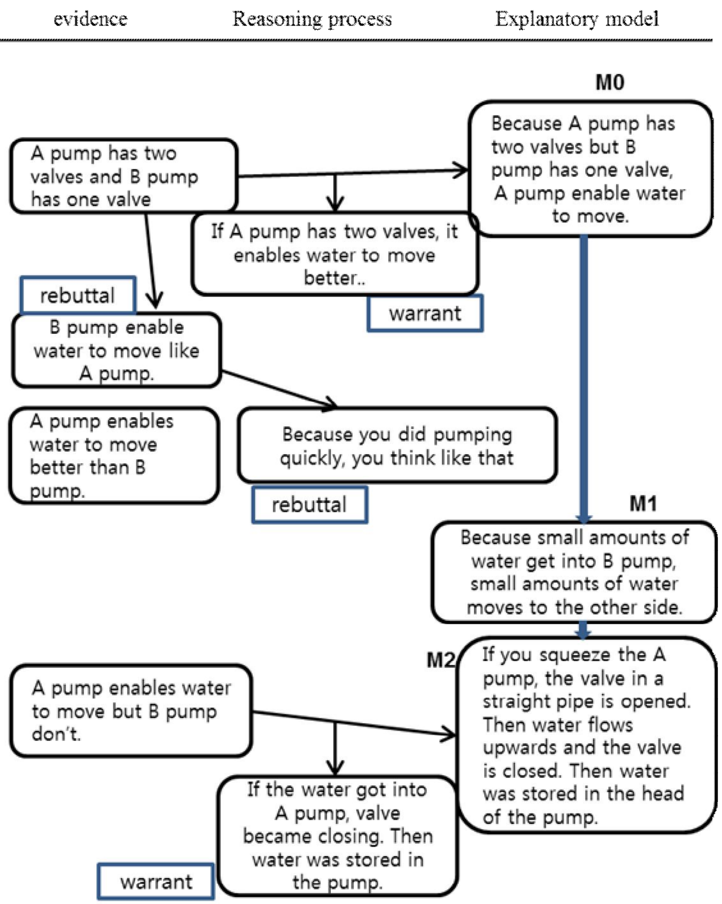


Figure III-11. Reasoning process in modeling phase 1 of Group B

4. Conclusions and Implications

This study aimed to explore the patterns of model development and the factors that lead to differences in reasoning (and in results) among several groups developing one-way circulation models. After analyzing the modeling-based lesson, the patterns of model development were identified as the *unchanged*, the *added*, and the *elaborated.* The patterns of model development were decided by interaction within group members; the *elaborated* pattern was the one that led to the strongest model development. The high-level reasoning process necessary for strong scientific argument (because it has the diverse elements of argumentation) was found in the *elaborated* pattern. The analogy model activity and the cognitive conflict within groups were the factors that influenced high-level reasoning. Accordingly, the initial model was justified and finally got to the target model.

The first purpose of this study was to identify the patterns of model developments. Modeling that was not collaborative led to the *unchanged* pattern because the leader generated the initial model that became the final model. However, the *added* and the *elaborated* pattern represented a collaborative modeling practice because more than two students engaged in the modeling discourse and the initial model became elaborated. In non-collaborative modeling, the alienating leader generated and compelled acceptance of the model; other students did not participate in the modeling process that was considered *critical revision*. The initial group model had no chance to develop so it closely matched or resembled the target model. Under a student leader with an alienating leadership style, students only modeled in the individual (as opposed to collaborative plane). Even worse, students were likely to learn the incorrect model.

In collaborative modeling, however, students contributed to constructing the final group model by participating in critical revision. In the case of the *added* pattern, more than two individual models were added by critical revision and became the final group model. In the *elaborated* pattern, the initial models developed in a way that eventually closely matched the target model by critical revision through both self-reflection and others' reflection. In this modeling process, the social interaction occurred through suggestions of models and revising critically by more than two students, and through participation in the reasoning process. Finally, the model could be developed on both the individual and the social/interactive planes.

The second purpose was to explore the factors that lead to high-level reasoning among those engaged in group modeling. One factor was the task feature. The reasoning processes were analyzed by the argumentation elements of Toulmin (1958). High-level reasoning was identified in the *elaborated* model development method found in modeling Phase 1, during which the siphon pump was used as the pedagogical analogy model of the heart. Students could observe the structure and function of the pump because it had a simple structure and function that was similar to that of the more-complex heart. This encouraged students to reason spontaneously and to interact with each other collaboratively. The other factor was the cognitive conflicts within groups that were revealed as the form of the rebuttals. The cognitive conflict within a group facilitated students to elaborate their own claims with diverse argumentation elements. Further, it made the initial model develop into the explanatory model close to the target model due to students' participation such as suggesting the rebuttals or raising questions.

Group modeling can be a "good" learning format because it enables students to learn in both the individual plane and the social plane. Appropriate teaching and learning materials and tasks are required to enhance interaction between group members. In this study, it was found that all groups did not engage in collaborative modeling automatically, though they received a task that asked for collaboration in its teaching and learning materials. Teachers need to create a group atmosphere that allows for spontaneous conflict and resolution in order to promote student–student interaction. In this group atmosphere, students can accept others' views with a permissive yet critical attitude. Engendering this atmosphere can take time, and the style of the different student leaders certainly influenced students' level of participation. Given this, teachers must decide how to group students together based on each student's individual features.

The models of groups without critical revision did not meet the target model due to absence of the teacher's intervention. Therefore, teachers should serve the role of guide for group discussion.

This study explored group model development of the blood flow in the heart, examining which methods for model development constructed models that were close to the target model. Unfortunately, there are some limitations: for example, individual students' internalizations were not examined and the lessons were only about the blood flow in the heart, and did not extend to the circulatory system. To overcome these challenges, further research should deal with the effects of group-modeling based learning on individual internalization, and examine the association between learning and modeling about the blood flow in the heart and learning and modeling about the overall circulatory system.

IV. Epistemological Features and Model Qualities Depending on the Model Evaluation Levels[2]

1. Introduction

Cognitive processes in science focus on explaining and predicting the physical world. Scientists construct models to represent and simplify complex phenomena, since it is impossible to study entities as they are (Buty & Mortimer, 2008). It is important for students to engage in modeling practices in science education. As they participate in the modeling processes, they develop epistemological understanding about scientific knowledge and knowing by evaluating and modifying the models (Schwarz *et al.*, 2009). In fact, models created by scientists go through similar processes. The empirical and conceptual criteria of these models are evaluated on an ongoing basis. If the models cannot meet the criteria, they need to be revised until they can be accepted by peer scientists (Passmore & Stewart, 2002). Likewise, students also experience how to generate, evaluate, and modify their models when engaging in modeling activities (Doyle & Ford, 1998). However, students have very little chance to be involved in modeling

[2] The study in chapter IV was published as follows: Lee, S., & Kim, H.-B. (2013). Exploring secondary students' epistemological features depending on the evaluation levels of the group model on blood circulation. *Science & Education*, DOI 10.1007/s11191-013-9639-9.

activities, and modeling activities in the science classroom are mainly presented as a way of describing scientific phenomena, rather than constructing scientific knowledge (Krajcik & Merritt, 2012; Lehrer & Schauble, 2012).

Modeling-based lessons should be provided for students in order to meet the goals of science education, which strives to enable students to experience epistemological understanding. In this regard, small-group modeling activities were designed in this study; students constructed their models and justified them until their models were accepted by other members. Small group interaction can cause cognitive conflicts among students who have different cognitive levels and learning tendencies (Kyza *et al.,* 2011). Through solving cognitive conflicts within groups, students can evaluate their own or others' models and develop their models by modifying them. Therefore, we could expect of students' models to be of higher quality, and modeling practice could be produced by participating in collaborative modeling activities rather than individual modeling activities. Schwarz *et al.* (2009) viewed modeling as a process of epistemological practices, and the process of students' epistemological practices was considered to be their learning progression.

Students' epistemological beliefs on science can be well presented in the phase of model evaluation (Buty & Mortimer, 2008; Oh & Oh, 2011). Among the beliefs introduced by Hofer and Pintrich (1997), the *certainty of knowledge*, *source of knowledge*, and *justification for knowing* can be well presented. In terms of certainty of knowledge, modeling evaluation processes either occurred or did not occur depending on students' points of view—that is, according to whether students viewed the models as conveying absolute truth, or as conveying tentative and evolving knowledge. In addition, the quality of models can be determined by whether the source of knowledge is authoritative or rooted in concepts for improving explanation by students. The process of justification for knowing appeared for the purpose of increasing the explanatory power of models. Accordingly, students actively participate in the model construction processes and high-quality models are often produced.

The study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels' aimed to identify the epistemological features that manifested in the model evaluation processes; the model-based lessons about "blood circulation" were designed for this purpose. Since collaborative learning cannot be detected in all small-group learning activities, "blood circulation" was chosen as the main topic in order to attract voluntary participation from students. Overall thinking skills are needed for students to understand the complex and interactive circulatory system. Exploration of blood circulation involves a wide range of scales that encompass both the visible (heart, veins and arteries) and the invisible (blood cells, oxygen, and carbon dioxide in a capillary) (Buckley, 2000). The topic of blood circulation would be appropriate for students to experience the modeling practice systemically. These three lessons have been designed based on group modeling with hands-on activities.

Epistemological understanding on models influences the epistemic process (Windschitl *et al.*, 2008): the higher the level of epistemological understanding (Sins *et al.* 2009; Windschitl *et al.*, 2008), the higher the level of reasoning and the higher the qualities of the developed models (Cheng & Brown, 2010; Schwarz *et al.* 2009). Hence, this chapter investigated the epistemological features depending on model evaluation levels in science classrooms and how the reasoning process and the model qualities would be influenced at a high level of model evaluation. In this study, it was not intended to match the epistemological features concerning model evaluation to the qualities of the respective models. Rather, it was attempted to identify the epistemological features in model evaluation that are likely to influence cognitive processes and model development.

2. Methods

2.1. Participants

A total of 34 middle school students in the second grade from K Girls' middle school of Incheon city, which is one of the metropolitan areas in Korea, participated in this study. They came from middle-class socioeconomic backgrounds. K Girls' middle school achieved a mid-upper level ranking in the national academic achievement assessment in 2011. Students worked in groups of three or four (nine groups) and the members for each group were decided on the basis of the students' academic achievement with the aim of having heterogeneity within each group. Responses to the pre-questionnaire showed that few students in this class had prior knowledge of blood circulation. Student labels were A, B, C, and D, and these alphabetic order indicate a descending order of academic achievement within the group. Group members had remained together during science class from the beginning of the semester so they were quite familiar with each other.

The teacher who participated in this study had an eight-year history of teaching science to secondary students and was in the doctoral program of science education. She had experience in examining small-group learning, especially as concerns argumentation, and had a strong interest in small group activities. She contributed to some aspects of the developed lesson. The teacher worked closely with the researchers to decide how to introduce the concepts of models and modeling and how to apply them to the lessons. Also, she engaged in revising the developed lesson of "blood circulation" with the researchers. The teacher had always supported the students' group activities before conducting this study, and she encouraged the students to actively take part in the group activities in the process of this study.

2.2. Context

It was not true that all students experienced the process of science in terms of practical epistemology when they participated in modeling activities in a small group. To help students construct their own models and criticize those of others' by employing evidence-based reasoning skills, three lessons about blood circulation were designed. These three lessons were designed with the following purposes in mind: to organize the lessons systematically, ensure that small group activities were done cooperatively, and ensure that the students understood the causal mechanism of blood circulation.

As described earlier, students can find it difficult to understand the concept of blood circulation because it is invisible and hard to experience (Buckley, 2000). Two kinds of strategies were used to minimize students' misconceptions: hands-on activities and diagram drawing. The first and second lessons consisted of hands-on activities so the students could experience practice with an analogous model and the dissection of a pig's heart. Doing this helped students obtain data for the third lesson, develop their representational skills for converting scientific concepts into a diagram or table, and maintain their interest in modeling. Additionally, the students used the drawing method for representing the model of blood circulation. The drawing method is appropriate for enhancing the understanding of scientific knowledge and for identifying the students' modeling performance

(Bamburger & Davis, 2013).

The goals of three lessons were to identify the structure of the heart, explain the mechanism of one-way blood flow in the heart, and depict blood circulation in the body. The first lesson was about siphon pump activity, which was used for the simulation of heart pumping. In this lesson, the students were requested to do group activities to explain the model in which the water flows in a single direction in the pump. The second lesson was about the anatomization of a pig's heart. The students could observe the heart structure and construct an explanatory model by applying the previous knowledge gained from the first lesson. Students had preconceptions of the heart's structure for preventing mixing of the oxygenated blood with deoxygenated blood, the mechanism of one-way blood flow in the heart, and the pumping role of the heart through these two lessons.

Then, in the last lesson, the students drew a diagram of blood circulation within the group setting. To construct the blood circulation model based on the models obtained in the previous lessons, the students needed overall thinking skills and autonomy. Accordingly, this study was conducted on the basis of the analysis of the modeling practice and the group models. Taking this approach was convenient for identifying the model qualities and modeling performances because the students constructed their models in both verbal and diagrammatic forms (Figure IV-1).

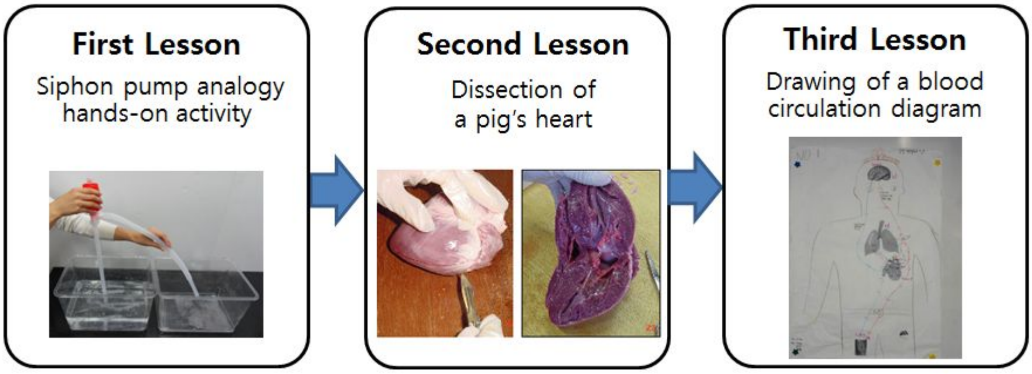


Figure IV-1. The implemented lessons of blood circulation

Because more comprehensive knowledge was required in the third lesson compared to the teacher-centered lecture, the modeling activities were guided by the teacher. The teacher gave each group a piece of paper, pictures of body organs, and red and blue pens, and briefly introduced the small-group activity during the first 10 minutes. During the following 25 minutes, the students were requested to do the actual group activities, such as outlining the human body, putting pictures of organs on it, and then marking the structure of the heart. In addition, they also had to link all the organs to the heart. They were given enough time to finish the pathway and then specify the oxygenated and deoxygenated blood and mark how gas exchange occurred in each organ. As a result, students combined several models such as the pulmonary circulation, the systemic circulation, and the gas exchange in lungs and other organs and completed the whole model of blood circulation. Among the nine groups, two of them voluntarily presented their models in front of the class. After that, the rest of the groups could revise their own models by comparing them with the two presenting groups' models in the last 5 minutes.

The teacher encouraged students to engage in spontaneous model evaluation process using the following four strategies. First, the lessons were not devised with a teacher-centered format, but rather with an open-participation format in terms of group modeling. Anderson and colleagues found that the frequency of a sequence of argumentative statements increased with an open-participation format (Anderson *et al.*, 2001). Second, students were given chances to receive some training and guidance in model evaluation during the first two lessons. Chances for specific training and help occurred two times during each lesson. Third, the teacher served in a helper role when students became confused concerning the development of models. Among other things, the teacher suggested scaffolding to facilitate the reasoning process anchored to some degree and encouraged students to self-evaluate their models. Fourth, students had the chance to revise other groups' models during the third lesson. Therefore, the lesson implemented in this study encouraged students' autonomy far beyond the traditional teaching and learning approach.

2.3. Data Collection and Analysis

Qualitative research was necessary to identify the students' epistemological features in the process of collaborative modeling activities. Since this study assumed that sociocultural aspects could have an influence on learning, a survey of not only the preconceptions but also the perceptions about a group activity and group norms were analyzed for all the students. When students represent their mental models as a form of language or physical object, students can identify their ideas clearly. By using this strategy in group modeling, students could construct the collaborative model by considering varying points of view (Windschitl *et al.,* 2008). Gobert (2000) found that drawing diagrams helped students construct the models and promoted revision and representational skills, so the students were asked to draw a blood circulation diagram in this study.

Subsequently, the students' blood circulation diagrams were analyzed to have a better understanding of their models. However, the diagrams alone were insufficient to understand the students' reasoning processes and the intermediate models they created. In this regard, as well as for the diagrams, videos that included the students' discourses and behaviors were employed to examine the development of the intermediate models. In other words, two kinds of models were analyzed, one in the form of diagrams and the other as an explanatory model represented in the discourse.

2.3.1. Framework for the process of model development

The mode for the process of model development used by Clement was modified to analyze the students' interactions and the process of model development (Clement, 2008, pp. 11-22). The process of development was examined by analyzing the utterances of both the student leader and non-leaders. Leaders in each group were identified based on the findings of Bianchini (1997) that students who actively participated in group discourse contributed to the group learning and had a higher position than other students within a group. Within each group, the academic achievements of the leaders were higher than those of the other students. They presented their ideas actively, gave scaffolding to others, and encouraged other students to participate in group discussion.

Figure IV-2 shows the framework for the process of model development. The utterances of the leader students and non-leader students are presented respectively in two different sections. As can be seen, students' utterances represent outward the line, while some omitted parts and meaningful behaviors are depicted in parentheses by the researcher. The rounded squares in the middle part represent the models, and are placed in order of development, i.e., M0, M1, M2, M3, and M4. The small squares show the order of the utterances. For example, A-5, in the small square, represents the fifth utterance of Student A. Moreover, the thin arrows represent the students' utterances and inferring models, while the thick arrows indicate the process of model development. A-1, D-2, and A-3 were contributed to build the initial model (M0), which facilitated the sequences such as D-4 and A-5 and developed into the intermediate model (M1). Use of this framework greatly facilitated examination of the generation, evaluation, and modification process of the models and also of the utterances and the students who contributed to the model development.

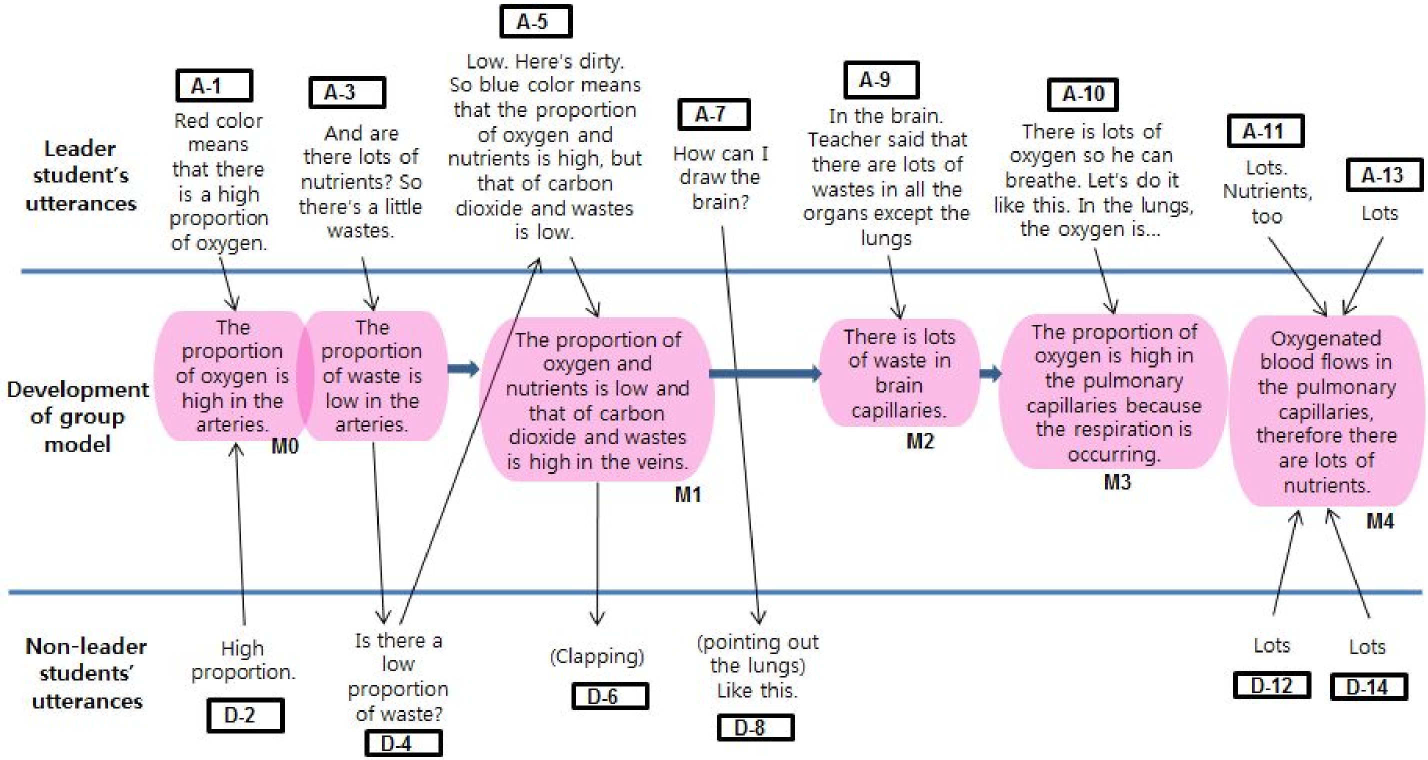


Figure IV-2**.** Framework for the process of model development. Group model: M0, M1, M2, M3; Student ID - Order of utterance: A-1, D-2, A-3....,D-14

2.3.2. Target model for the blood circulation

Two kinds of target models of the blood circulation were identified as representing the key idea (Figures IV-3 and IV-4). The model qualities were examined in terms of the explanatory nature of the models. Figure IV-3 clearly shows the blood circulation pathways and was used when analyzing the students' diagrams. The students needed to understand that the whole structure of the heart, such as right/left atriums and right/left ventricles, and the terms related to the vessels, such as pulmonary veins/arteries, should be correctly marked in the right places. Also, they needed to know where the organs and muscles were placed and correctly connect them to the heart. The blood circulation pathways can be mainly divided into two parts: *pulmonary circulation* and *systemic circulation*. While pulmonary circulation is the pathway connecting the heart and lungs, systemic circulation indicates the pathway between the heart and each organ and muscle. Oxygenated blood should be marked as red on the blood vessels that carry blood outward from the lungs to the heart and from the heart to each organ and muscle. On the other hand, deoxygenated blood, which carries blood from the heart to the lungs as well as conveys blood outward from each organ and muscle to the heart, should be marked as blue. Moreover, students were asked to explain how gas exchange occurred in the lungs, in each organ, and in muscles.

Figure IV-4 is the visualization of the target model introduced in

Buckley and Boulter's study (Buckley & Boulter, 1996, p. 128). This model has been used for comparing the students' explanatory models represented in this discourse, which are focused on the various mechanisms pertinent to blood circulation, such as the heart's role of pumping and gas exchanges in the lungs and other organs. The structure of the objects is placed in the boxes; the explanations above the arrows represent the actions, and the bigger square boxes show the mechanism.

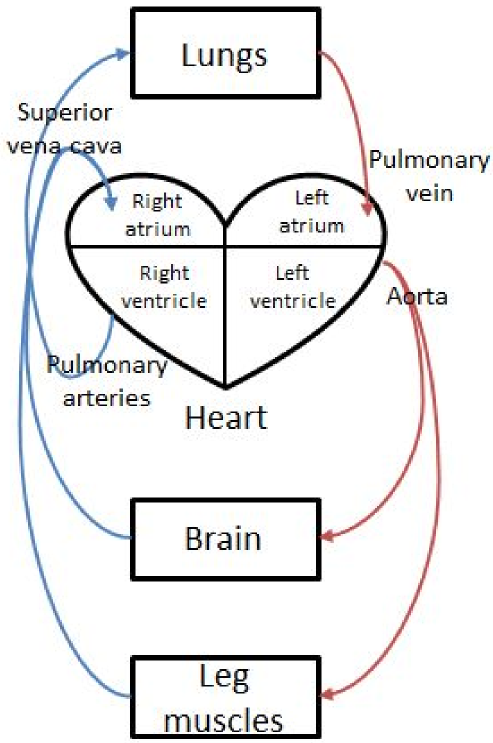


Figure IV-3. Target model represented in drawing of the blood circulation

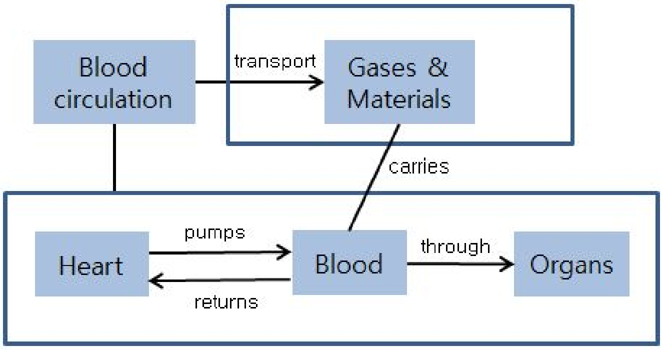


Figure IV-4. Target model represented in discourse

2.3.3. Framework for levels of epistemological features depending on the model evaluation

A framework concerning students' epistemologies has been developed by analyzing modeling processes and metamodeling (see Table IV-1). This framework was based on one of learning progression dimensions, the "models as changeable entities" identified by Schwarz and his colleagues (Schwarz *et al.,* 2009, p. 647). This notion focuses on how students understand the changes in their models and compare and evaluate their models in order to communicate with each other and better explain scientific phenomena using evidence. Hence, the focus also rests in the model evaluation processes, since model dynamics can be well reflected in this phase. On the other hand, epistemological features were concluded inductively by analyzing the reasoning process that emerged during the process of model evaluation.

As shown in Table IV-1, four evaluation levels are presented according to the students' performances. Their performances are related to their understanding of whether or not the models are changeable and to the source of evidence, such as authoritative sources, the superficial component of models, and the explanatory nature of models. Level 1 indicates that students see models as unchangeable and that they do not justify the models using scientific reasoning. At Level 2, they consider that models can be changeable, but their criterion of model evaluation is based on authoritative sources. Model justification is not based on scientific reasoning but authoritative knowledge that they believe to be absolute knowledge. Students' performances change at Level 3, at which the superficial component of models is considered to be the optimal model evaluation criterion. Yet, with Level 3 students only attempt to use superficial criteria such as *aesthetics and features* and *terminology.* Despite the superficial level of the criteria, their attempt to justify the models can be seen; as a result, the models are only modified on the superficial level. At Level 4, students evaluate the model using more comprehensive criteria such as *processes* and *mechanism*. With Level 4 in particular, cognitive conflicts among group members surface and influence performance of the group, but some chain reactions involving cognitive reasoning emerge and the models become more sophisticated. This is because the evaluation criteria require higher level understanding of topics related to how scientific phenomena occur. The evaluation criteria for model explanation follow the definition of

Nelson and Davis (2011) (see Table IV-2), which emphasizes *aesthetics and features*, *terminology, processes*, and *mechanism*.

To ensure the reliability of the results, the author and the other person who was a PhD student carefully proceeded through every step from framework development to data coding. After developing the framework, each person independently conducted data coding in terms of model evaluation and modeling practice levels. If anyone found differences in data coding, they tried to achieve a consensus through discussion.

Table IV-1. Levels of model evaluation and epistemological features

Level	Performance	Epistemological features
1	Students do not evaluate the models	Students neither justify the models nor modify the models by applying scientific reasoning
2	Students revise models based on information from authority such as a teacher, a textbook, a peer and so on.	Students justify the models not through the use of scientific reasoning, but through use of authoritative sources that they regard as possessing the absolute truth.
3	Students evaluate the models using superficial criteria such as *aesthetics and features* and *terminology* that are the superficial components of the models related to communication	Students justify the model with evaluative epistemology, but their justifications are based on simple comparison of the superficial aspects of the model. Thus, their models become more elaborate on the superficial level.
4	Students evaluate the models using more comprehensive criteria such as *processes* and *mechanism* that related to the explanatory nature of the models about phenomena..	Even if cognitive conflicts exist among group members, they solve problems by justifying their own claims using more comprehensive criteria. This process leads to the chain reaction of cognitive reasoning with the evidence. They seem to have evaluative epistemology. The group model ultimately becomes more sophisticated because of the justification that occurs during the process of reasoning. They seem to understand the explanatory nature of models.

Table IV-2. Coding scheme for model evaluation criteria (Nelson & Davis, 2012, p. 1940)

Code	Explanation
Aesthetics and features	Students comment on model criteria/components: neatness, artistic quality, arrows, labels, key, zoom view title, and internal consistency.
Mechanism or process	Students mention change over time, process, mechanism, causality, and/or variables or influential factors that govern the phenomenon.
Terminology	Students cite the use of scientific terms and/or proper use of terminology.

3. Results and Discussions

In this section, the performances according to the model evaluation levels and the epistemological features found in the science classroom were presented. The model evaluation levels were categorized by levels one through four, based on the evaluation criteria as well as on an understanding of the changeable nature of models and the explanatory nature of the model. The modeling performances influenced model quality. When more comprehensive criteria were used during model evaluation, cognitive reasoning chains were present during the modeling process.

3.1. Epistemological Features and Model Qualities Depending on the Levels of Model Evaluation

3.1.1. The phase without model evaluation

The process of justifying models was not expressed by students in the first level, because they did not evaluate and rebut the model. It may be constructed that students were demonstrating an absolutist epistemology, but this is not accurate; rather, in this phase students might have thought it unnecessary to evaluate the model. Concepts in blood circulation that were modeled included pulmonary circulation, systemic circulation, gas exchange in the lungs and other organs, one-way blood flow in the heart, and so forth. These concepts had sub-concepts with variable ontological categories, and students had different understandings depending on these conceptual variations.

The ontological category of blood circulation is an emergent process, because the means of delivering blood to each organ happens randomly, and the elements of the heart, blood vessels, and blood interact with each other, triggering the mechanism (Chi, 2005). By just focusing on the single pathway of pulmonary circulation, however, students would understand pulmonary circulation better than systemic circulation. This is because pulmonary circulation has a single pathway, but systemic circulation has multiple pathways. For this reason, this study assumed that it would be easier for students to represent the pulmonary circulation model, and modeling of pulmonary circulation would be found in all cases at Level 1. However, there were only two cases out of twenty-seven modeling processes that led to Level 1. This is because the students in this sample actively participated more in the discourse and modeling practice than did other school students.

Figure IV-5 sets out the discourse that students in Group 8 used when discussing pulmonary circulation. A leader in the group completed the pathway of pulmonary circulation that connects the organs. Although the leader generated an incomplete model that lacked the transportation of gases and the gas exchange mechanism, there was no model evaluation or modification. Students focused on visualizing the structure and the pathway of pulmonary circulation, which is an obvious phenomenon at this level. In contrast, the function and mechanism of blood circulation, which requires deeper thinking to understand, had not yet been taken into consideration. As a result, the group's model of pulmonary circulation lacked the mechanism that blood uses to transport gases and materials. A detailed model of Group 8 is shown in Figure IV-6.

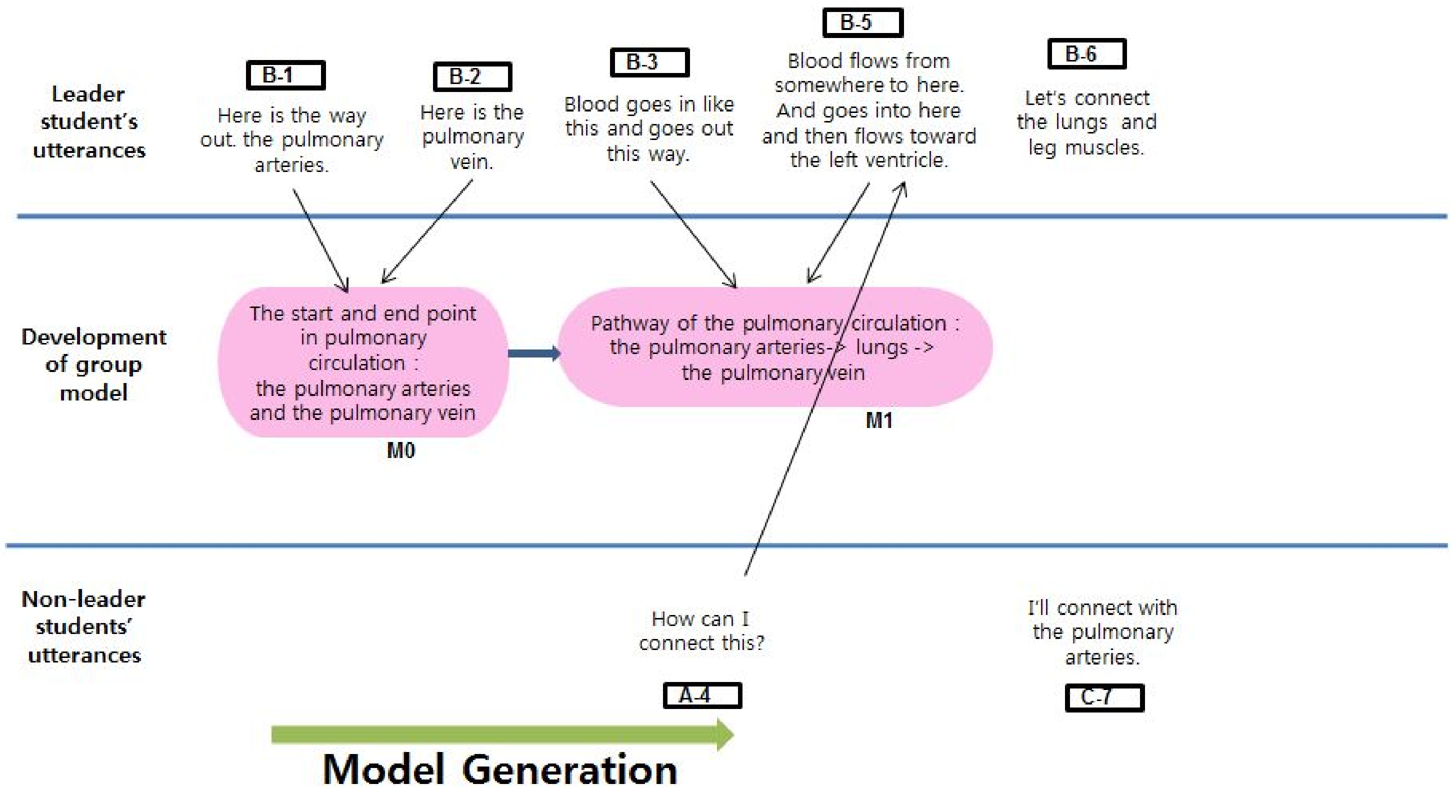


Figure IV-5. Discourse during Group 8's model development of pulmonary circulation. Group model: M0, M1; Student ID- Order of utterance: B-1, B-2, B-3….,C-7

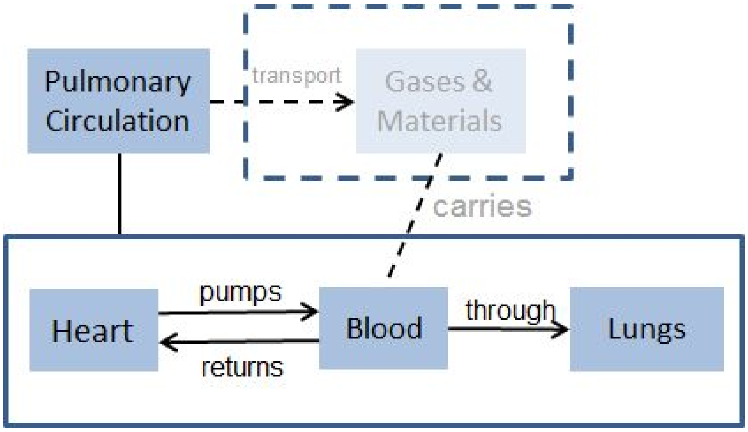


Figure IV-6. Group 8's discursive model of pulmonary circulation

3.1.2. The phase of model evaluation using authoritative sources

Students at Level 2 were likely to evaluate models using evidence from authoritative sources such as teachers, high achievers, textbooks, and so forth. In fact, students evaluated the models constructed in their groups because they knew their models were not perfect. However, deeper consideration about functions and mechanisms of blood circulation did not emerge at this stage. Students did not consider the explanatory nature of models as evaluation criteria. They seemed to have an absolutist epistemology as they perceived the changeable nature of models, yet regarded the authoritative sources as the absolute criteria. Absolutists perceive knowledge as absolute and emphasize authority as evidence of knowing (Kuhn, 1991, p. 173). Students in this case wrongly adopted the authoritative information, and non-leader students did not play the role of critical listener. As a result, misconceptions in the group model were not revised.

In Group 4's case, lecture notes hindered the revision of the systemic circulation diagram, which is used as a criterion of model evaluation. As can be seen in Figure IV-7, Student A tried to evaluate the blood circulation diagram by comparing it with diagrams in the textbook (A-6). However, she changed her mind when Student B showed her the lecture notes (B-7), and she used the notes as an evaluation criterion instead of the textbook. Later she repeated the quotes from the lecture notes—"Blood flows via the whole body and goes to the superior vena cava" (A-9)—and ceased further revision of the concept.

Taking a closer look at Group 4's explanatory model represented in discourse (Figure IV-7), its systemic circulation starts from the left ventricle and goes to the pulmonary vein. In this sense, the students perceived the principle of blood circulation as pressure, as it is clear they believed the heart is the power source of blood circulation. However, in the blood circulation diagram (Figure IV-8), systemic circulation is represented as a linear concept, meaning that the blood starts from the lungs and is then transported into the arm muscles, from which it then flows into the leg muscles and brain before returning to the heart in a stepwise fashion. As can be seen from the inconsistency between the model described in discourse and the model represented in the diagram, students did not understand the mechanism by which the heart powers the circulation of the blood. It is worth reflecting on the fact that students were given somewhat fragmentary knowledge concerning the left ventricle as the starting point of the circulatory system.

The diagram model of Group 4 had two kinds of misconceptions (Figure IV-8). The first misconception was that oxygenated blood flows directly from the lungs to each organ without passing through the heart. The other misconception was the linear concept, whereby the blood starts from the heart and finally flows back to the heart after passing through each organ. In this case, students had an incorrect understanding of systemic circulation. This misunderstanding resulted from the simpler explanation written in the lecture notes. Student A-3 and A-5 wrote, “Blood flows via the whole body and goes to the superior vena cava,” when he was listening to the teacher’s instructions. In fact, the original and correct concept was “Blood flows outward from the heart to each organ through the distributed pathways and flows back to the heart again.” The utterance of Student A-3, “flows via the whole body,” could be evidence of how this misconception occurred. This is consistent with the finding of Arnaudin and Mintzes (1985) that misconceptions originate from teachers’ instructional methods.

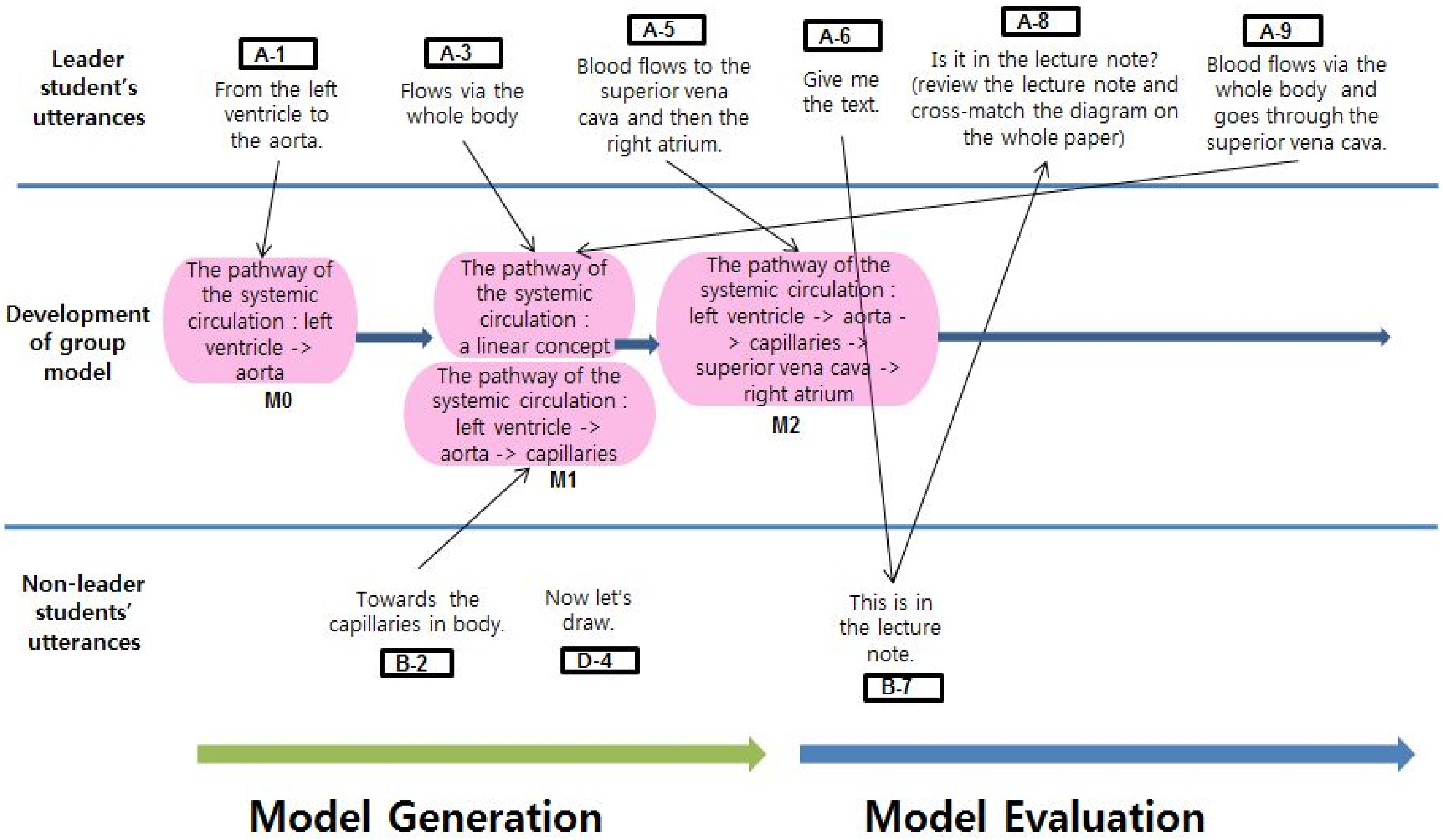


Figure IV-7. Discourse during Group 4's development of the model for systemic circulation. Group model: M0, M1, M2; Student ID- Order of utterance: A-1, B-2, A-3.…,A-9

The passive participation of those students not playing leadership roles could be another cause of the error that surfaced. Their passive attitude toward group discussion might mean that they agreed with the student leaders' opinions. Students in Group 4 did not demonstrate behavior associated with critical listeners. However, it is not true that only the student leader was involved in model construction, as both Students B and D had participated in the modeling practice, and Student D expressed her opinion. Unfortunately, they were not involved in the meaningful cognitive process. Indeed, none of them expressed a different opinion when Student A evaluated the model according to the authoritative source, the lecture notes.

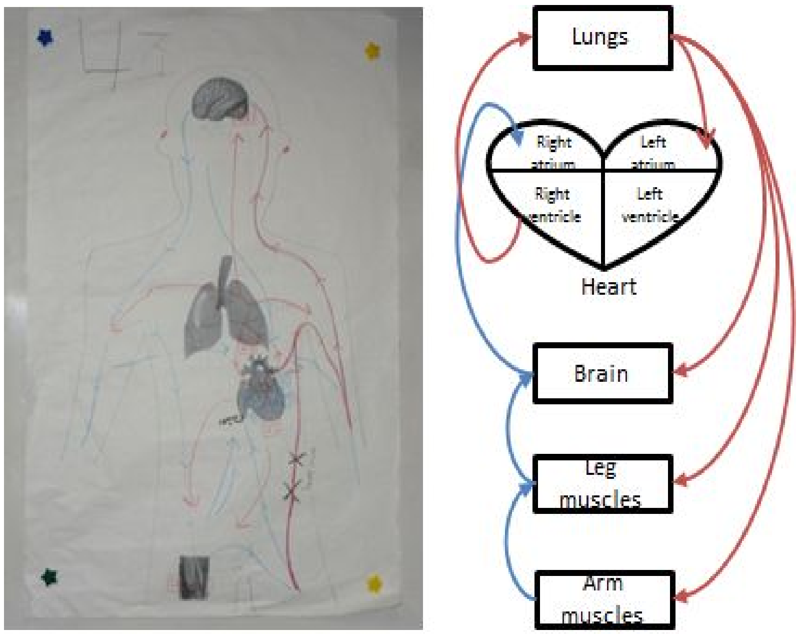


Figure IV-8. Group 4's diagram model of systemic circulation

3.1.3 The phase of model evaluation using superficial criteria

Students tended to evaluate the superficial model components by presenting the evaluative epistemology. People who use evaluative epistemology consider the adequacy of multiple views and understand the concept of comparing or evaluating variable points of view (Kuhn, 1991, p. 188). But the students used superficial criteria for evaluating the appropriateness of the model, such as *aesthetics and features* and *terminology* which were model components. The superficial criteria could be important evaluation criteria because it might help students communicate ideas with others and make others understand models (Bamburger & Davis, 2013). However, revisions to the group model were based on aesthetic aspects as opposed to a mechanistic explanation of the phenomena. Students seemed to consider the role of model as description of phenomena at Level 3.

In an example of Level 3 understanding, students evaluated the model using a superficial criterion, *aesthetics*. As shown in Figure IV-9, all students in Group 6 actively participated in the modeling process by questioning the figure of a hand. Their questions were related to the model evaluation, and *aesthetics* were employed as a criterion. Student A explained her intention of expressing the figure of an open hand to justify her own model (A-15), which showed an epistemological feature that did not justify her model based on the function or the mechanism of blood circulation.

Taking a look at the revision process of systemic circulation of the hand, Student C also focused on the aesthetic aspects, asserting that there should be fingers in the diagram (C-16). As a result, the blood vessels in the hand and the leg in the diagram are like an open blood-vascular system. Though this group did not make a major mistake, such as the linear concept mistakes made by Group 4, the open blood-vascular system error was represented in their diagram (see Figure IV-10).

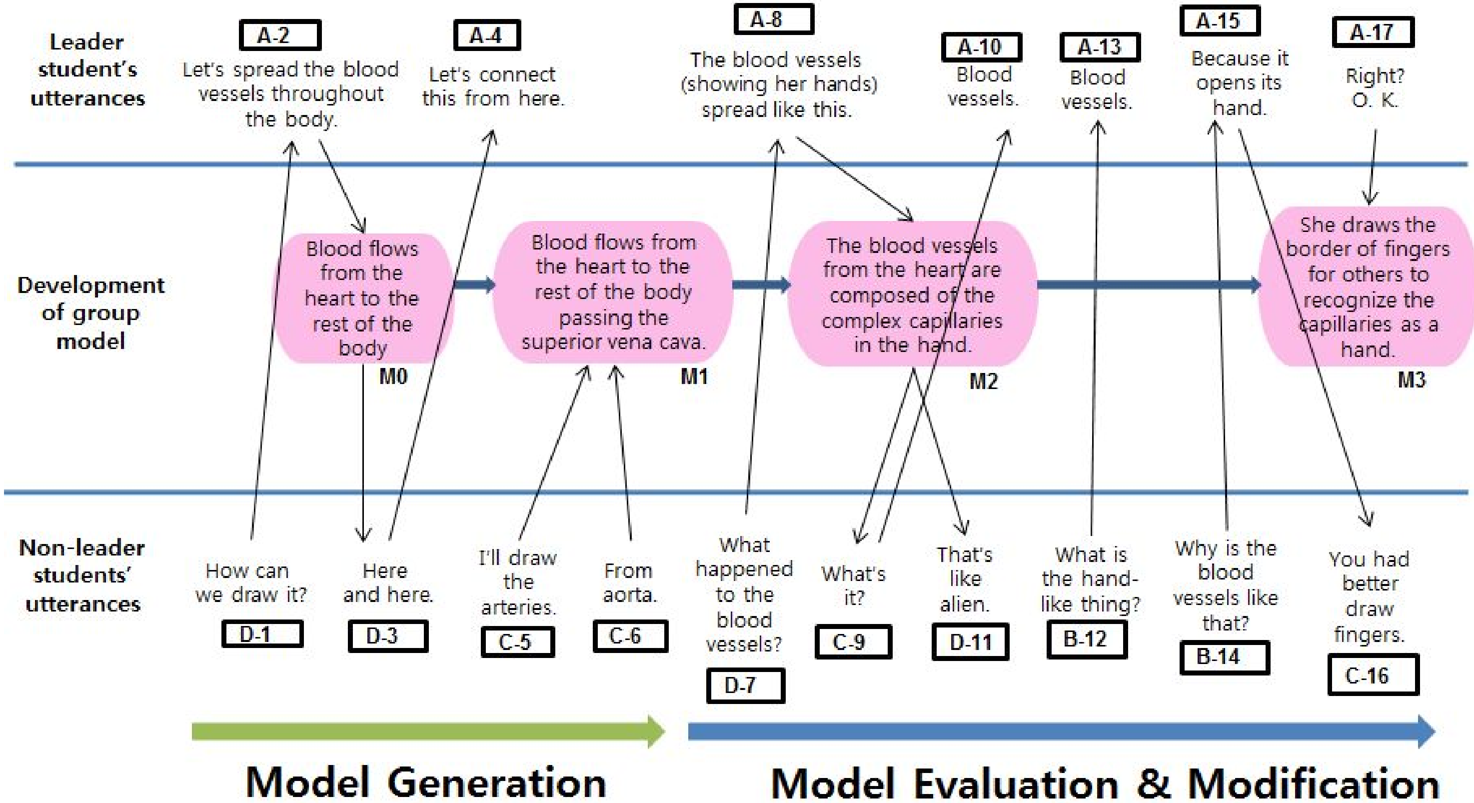


Figure IV-9. Discourse during Group 6's model development of systemic circulation. Group model: M0, M1, M2, M3; Student ID- Order of utterance: D-1, A-2, D-3….,A-17

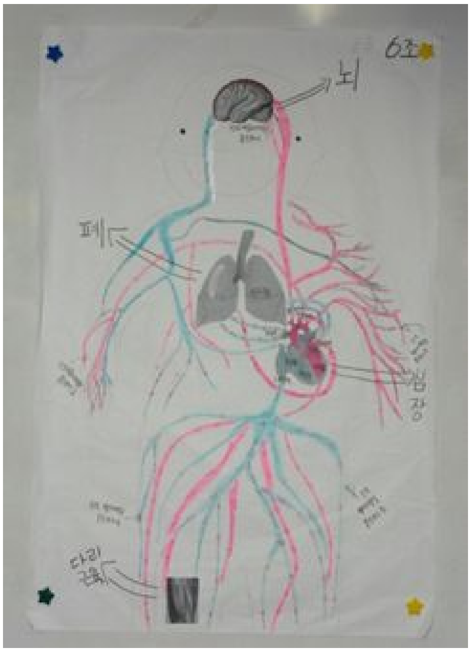


Figure IV-10. Group 6's diagram model of blood circulation

3.2. The Highest-Level Model Evaluation Process

Only three of twenty-seven cases of modeling were found that represented Level 4 of model evaluation. Students at this level showed evaluative epistemology through the use of more comprehensive criteria such as *processes and mechanism* to evaluate the explanatory nature of their models. They understood the role of model as explanation of phenomena which might be complex and invisible. According to the analysis, there was cognitive conflict within a group in the process of monitoring. This cognitive conflict occurred when students asked questions to check their own understanding, or to revise incorrect concepts by checking the understanding of others. This type of checking and verification of understanding is a metacognitive activity.

Metacognition refers to the skills that enable learners to understand and monitor their cognitive processes (Schraw *et al*., 2006). Since small-group modeling activity involves collaboration between several people to construct knowledge, metacognition occurs not only in an individual learner, but also among individuals. Throughout this activity, learners can identify the constructed models using metacognitive skills. Accordingly, the model also undergoes a process of evaluation, revision, and elaboration in terms of a chain of cognitive processes. At Level 4, students could engage in authentic modeling process, which enabled to give students chances to reason scientifically concerning practical epistemology (Svboda & Passmore, 2013). These findings reinforce previous studies describing how conflict among different views affects genuine interaction and can impede revision and development of an original theory (Hofer & Pintrich, 1997).

3.2.1. Checking self-understanding: Raising questions

From the perspective of conceptual change, cognitive conflict refers to the inner conflict that occurs when learners try to transform their "naïve knowledge" into scientific knowledge in order to learn a new concept (Dreyfus *et al*., 1990, p. 555). When students use the Socratic Method to identify their preconceptions and become aware of how they differ from other views, cognitive conflict may be triggered (Champagne *et al*., 1983). It should be noted that, during the modeling activity, there was a finding of cognitive conflict among those at Level 4.

As shown in Figure IV-11, a student raised a question in order to monitor her own understanding, when she noticed that another student's mental model was different from her own prior knowledge. Questions asked of students have an effect on self-reflection and self-monitoring skills (Chin & Osborne, 2008). In this case, cognitive conflict showed up on the social plane, and generated a series of cognitive processes such as monitoring by the student of her own understanding, along with the generation, justification, evaluation, and modification of the model. As a result, the group model was revised through the aspect of *process*: that is, having more comprehension.

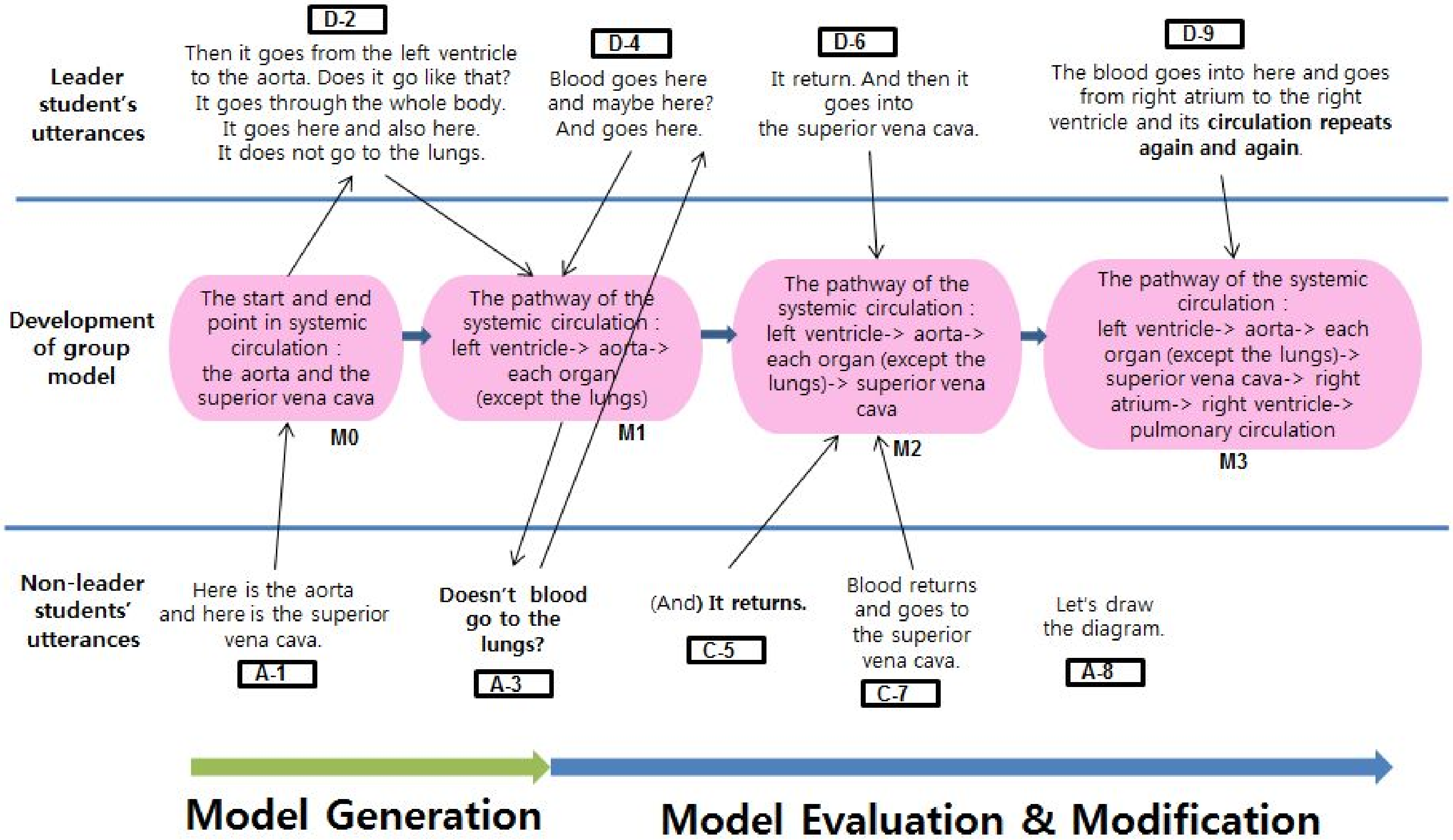


Figure IV-11. Discourse during Group 1's model development of systemic circulation. Group model: M0, M1, M2, M3; Student ID- Order of utterance: A-1, D-2, A-3….,D-9

Taking Group 1's experience, for example, both Students A and D were constructing the systemic circulation model (A-1 and D-2). Student D said blood flows from the aorta to each organ following the distributed pathways, and it does not go into the lungs (D-2). Then Student A asked, "Doesn't blood go to the lungs?" (A-3). This question expressed the cognitive conflict among group members potentially being experienced in this small group. Because Student A requested the justification of Students D's statement (D-2) which was different from her own idea. The question also served as a mechanism for solving the cognitive conflict among group members, because asking the question required an answer as to whether or not blood goes into the lungs. In addition, this was an example of model evaluation using the criteria of *process* of the phenomenon, because Students A and D articulated their understanding as an expressed model to help their thinking and develop group consensus (Nelson & Davis, 2012).

At the same time, Student D could identify the concept of distributed pathways and check the modeling process when she answered this question (D-4). At the same time, Student D pointed out the pathway for justifying her own claim. The utterance made by Student D (D-4) in response led to a subsequent model evaluation. For example, Student C evaluated Student D's utterance, pointing out that some pathway of circulation was missing in Student D's utterance and modifying it by referring to the movement of the blood from each organ before returning to the heart (C-5). Later, she emphasized the point again, that blood returns to the heart after going through each organ (C-7). Her modification contributed to the clear depiction of blood circulation in the group's model. Moreover, Student D's rephrasing of the issue emphasized the round trip idea of blood flowing in a continuous circle from the heart to the body (D-9). She did not just arrange the blood circulation pathways; instead, she focused on the repetitive process of circulation, which extended the meaning of the model of systemic circulation. She acknowledged and shared the meaning that blood circulation was categorized as an emergent process through a group discussion. In this regard, the questioning that occurred during the process of constructing the model led to a cascade of generative activity. It not only solved the cognitive conflict among group members but also promoted a chain of cognitive processes in terms of authentic modeling process that contributed to the elaboration of the model (Chin & Osborne, 2008).

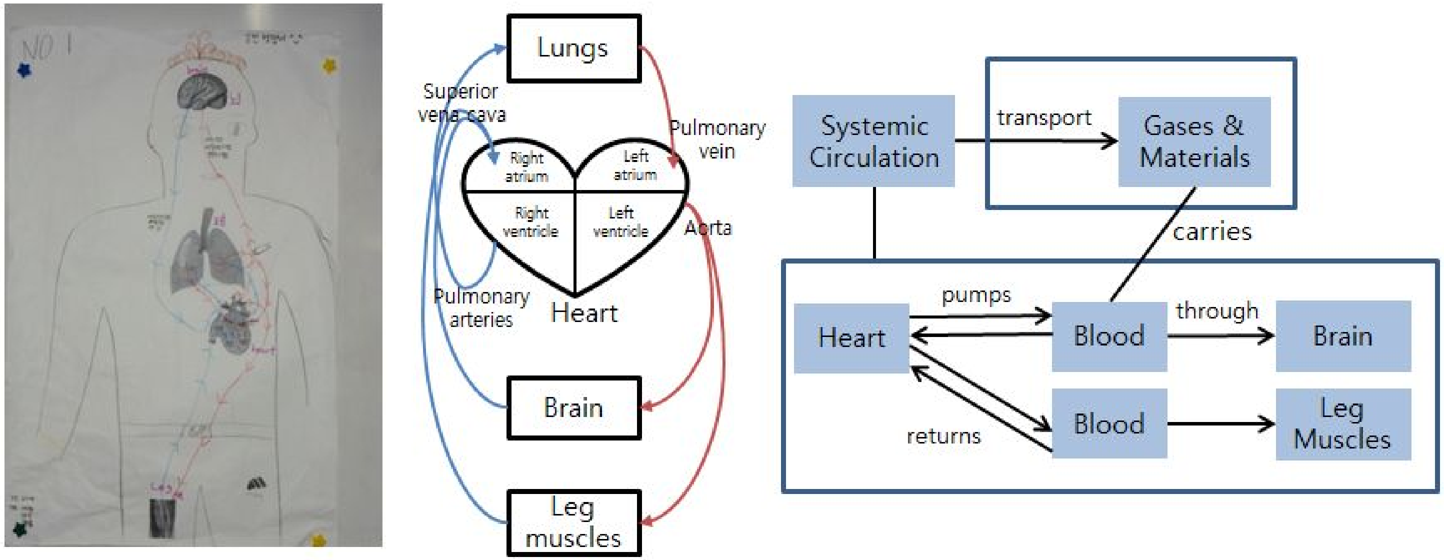


Figure IV-12. Group 1’s diagram model of blood circulation and discursive model of systemic circulation

Along with the diagram of Group 1, the explanatory model represented in the discourse (Figure IV-12) provides an accurate representation of systemic circulation. When they drew the diagram, they first figured out the starting point and the finishing point of the blood circulation system (the heart) and then arranged the structures as well as the pathways. It could be inferred that the students understood that the heart works as a pump, even though there was no explicit statement to indicate this. Actually, this assumption is supported by the fact that their blood circulation diagram reflects their clear understanding of the scientific concept of the systemic circulation distributed pathway. This finding shows that they evaluated the model by asking a question that request the explanation of a process in terms of sense-making. An epistemological feature should also be noted, i.e., students generated the systemic circulation using discourse and showed scientific reasoning process through justifying their own claims during a model-based inquiry, which cannot be represented by the two-dimensional diagram.

3.2.2. Monitoring others' understanding: Emergence after expression of an incorrect concept

Cognitive conflict among group members occurred when someone tried to construct the model with an incorrect concept, and it was solved with the help of peer monitoring. This behavior engages learners in a chain of cognitive processes. Students evaluated the explanatory nature of models using more-comprehensive criteria such as a process or a mechanism. Accordingly, they justified their claim with their own reasoning. Students were elaborating on the model and connecting it to their knowledge, which could either have been gained from the task at hand or have been held beforehand (Sins *et al.*, 2009).

An episode selected from Group 6 illustrates this case (see Figure IV-13). When Student D tried to use an incorrect concept to construct the model (D-2), Student C immediately pointed out the mistake and revised it (C-3). This helped Student C externalized her own model in terms of explanation of the pulmonary arteries (King, 1994). She evaluated the model using the criterion of the model's structure and modified the model to show that the pulmonary artery is an oxygen-poor vessel. In addition to the revision, she also showed the simple structure of argumentation by suggesting the reason that warranted the marking of a blue line on the pulmonary arteries (see C-7). Through her explanation, Student D was able to replace a previously held incorrect concept with the correct concept, and she could then participate in the modeling actively. This extended model caused Student D to begin self-monitoring, which was expressed as questioning (see D-8). Her question concerned the mechanism of gas exchange in the lungs, a new concept that had not been mentioned in Student C's statement. Student D was then able to evaluate the existing model.

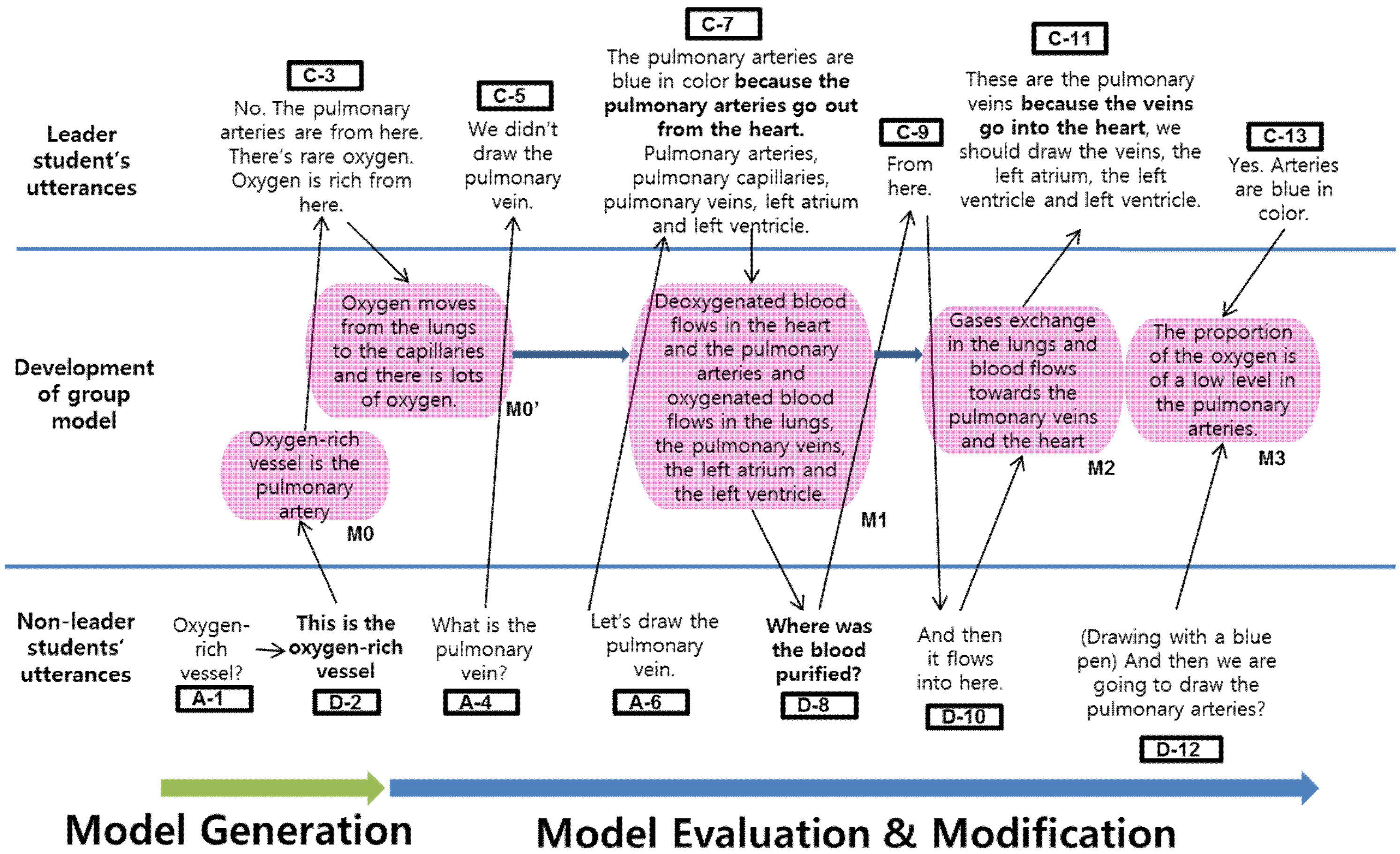


Figure IV-13. Discourse during Group 6's model development of pulmonary circulation and gas exchange. Group model: M0, MO', M1, M2, M3; Student ID- Order of utterance: A-1, D-2, C-3….,D-13

As a result, cognitive collaboration was taking place in the modeling process. In other words, Student C's explanatory model helped Student D's learning, while Student D's questions gave Student C the clue that enabled her to elaborate on the model. In a related study, "bi-directional scaffolding" within group peers was found (Goos *et al.*, 2002, p. 196). In light of this, it can be believed that there was interactive scaffolding taking place between Students C and D. At first, their model about circulation was incomplete; however, it became complete as they emphasized two facts: the pulmonary vein as an oxygen-rich vessel and the mechanism of gas exchange in the lungs. As a result, they could evaluate their model with more-comprehensive criteria. Student D's utterance—"purified"— (see D-8) is actually a spontaneous term, not a scientific term, but it led the discussion to gas exchange, which is an important mechanism in pulmonary circulation. This discourse is an example of how one student provides scaffolding for another student, which helps the student to know the mechanism within her the zone of proximal development (ZPD). This was because they achieved two goals, revising the wrong concept and sharing the revised concept.

The explanatory model represented in discourse, on the social plane, was internalized by individual students, which was to say that the group model became shared knowledge among group members. The fact that students showed confidence in their understanding of blood circulation in the questionnaire administered at the end of the study could support this internalization. Student D's participation in the cognitive process might also have emphasized the distributed knowledge (D-10). In other words, the question raised by Student D (D-8) brought attention to gas exchange. As can be seen in C-11, Student C gave a clear explanation about gas exchange and also clarified the position of pulmonary veins, constructing the model in the process of justifying her opinions (see C-11). They represented not only the structure and the pathway but also the reason why the pulmonary arteries and the pulmonary veins existed as they did with their own knowledge. This demonstrated the epistemological process of knowing.

The diagram made by Group 6 represents the result of cognitive collaboration. Only the structures and pathways can be identified in Group 6's diagram (see Figure IV-14). However, their discourse revealed that they had generated this model perfectly, including its mechanism, through cognitive interactions among themselves.

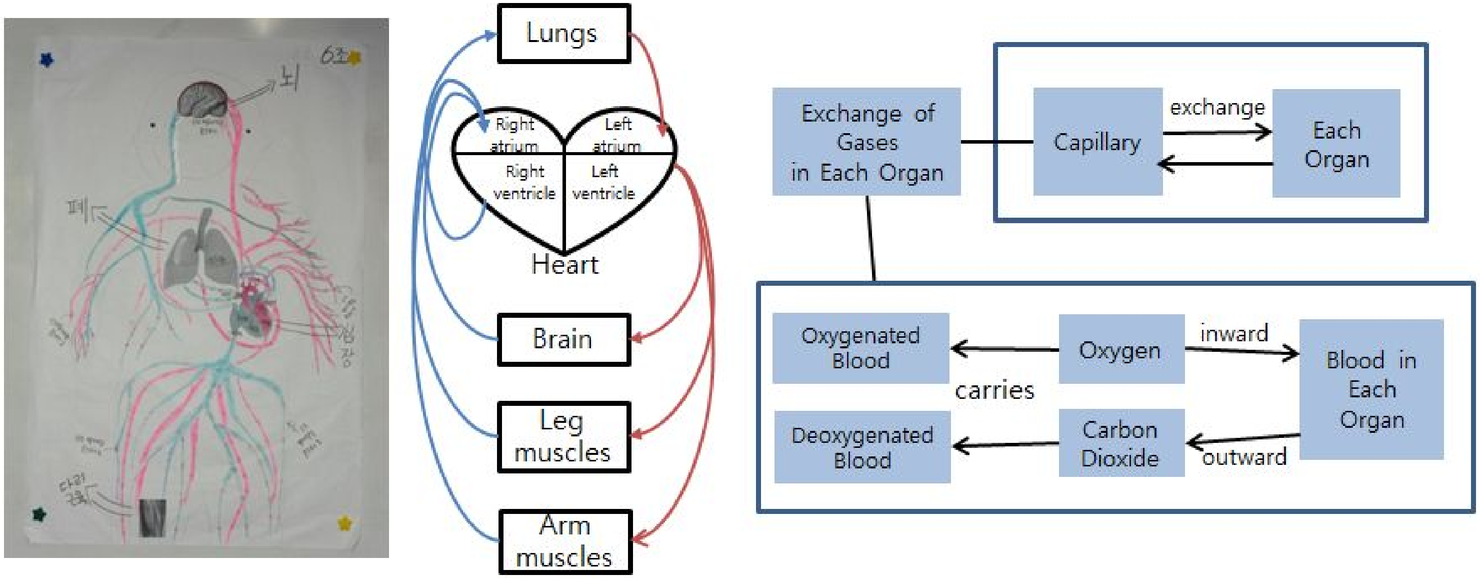


Figure IV-14 Group 6's diagram model of blood circulation and discursive model of exchange of gases

4. Conclusions and Implications

This study aimed to identify the epistemological features of the group modeling process about blood circulation, which is an emergent process based on Chi's (2005) ontological category. The assumption is that students' epistemological ideas can be expressed when they participate in the group modeling situation of generating and evaluating knowledge (Sandoval, 2005). Model evaluation levels were categorized based on several criteria and on the levels' epistemological features. The chain of cognitive reasoning was found in the context of a high level of model evaluation. These findings have implications for the goal of science education in terms of developing students' epistemologies.

The first purpose of this study was to explore epistemological features and model qualities depending on the model evaluation levels. The model evaluation levels were defined as Levels 1 to 4 based on the evaluation criteria; the higher levels reflected a greater depth of critical thought and metacognitive monitoring concerning the changeable nature of models and the explanatory nature of the model. Students that expressed an absolutist view regarded authoritative sources as conveying absolute knowledge; conversely, students displaying an evaluative epistemology used evidential reasoning to justify their own claims and to criticize the claims of others. The models in Levels 1 through 3 were not able to represent the emergent process of blood circulation, and some models had misconceptions, such as the lungs serving as the pumping origin of blood and the linear concept of blood circulation.

Level 1 of the model evaluation mainly occurred when students engaged in modeling of pulmonary circulation. This was because students could not have thought of the necessity of change; in other words, it was shown that the evaluation performance depended on the ontological categories of models. At Level 1, the target model for pulmonary circulation had a single pathway through which circulation occurred, which was much simpler than systemic circulation with multiple pathways. This simplicity led students to recognize the pulmonary circulation as a direct process and to easily construct the model by focusing only on this single pathway; due to this ease, students did not evaluate and modify the model.

At Level 2, students recognized the necessity of revising the model; the evaluation criteria were authoritative sources. As students justified their models and evidences through comparison with authoritative sources rather than their own reasoning, they perceived the sources as being absolutely true; that is, in terms of an absolutist epistemology. For this model, the misconception existed in the content of the teacher's lecture, which was written incorrectly; this served as a criterion for evaluating the model.

At Level 3, students demonstrated evaluative epistemology by using their own reasoning to evaluate the model. However, they reasoned by comparing the model with superficial criteria. As a result, only the aesthetic features of the models were further developed beyond the epistemology in

Level 1 and Level 2. Students did not understand the goal of model as explaining the phenomena.

The second purpose was to identify the epistemological features in terms of the cognitive reasoning process for understanding the context of Level 4 model evaluation. At Level 4, students evaluated the explanatory nature of the model in terms of the processes and the mechanisms of the phenomena depicted. This evaluation was based on the epistemological belief of knowing that the model constructed within a group should be evaluated for further development and alteration. Cognitive conflict within a group was the main cause of these features, and it was triggered when students attempted to use metacognitive monitoring to examine their own or others' understanding. Students actively participated in cognitive processes in order to solve cognitive conflict among group members; they also evaluated and justified the explanatory nature of models with more comprehensive criteria, such as whether the models accurately depicted mechanisms and processes with respect to the circulatory system. The model for circulation was then elaborated on.

From a sociocultural perspective, knowledge is constructed in a social plane and human mental processes are context-dependent (Wertsch, 1991). Learning effects can be enhanced by engaging learners in group activities. Indeed, learning that reflected a sociocultural perspective was clearly shown at Level 4 of the model evaluation. When students were requested to engage in group modeling, they shared their own mental models with group members, allowing each individual's degree of understanding to be identified as the groups worked together. Interactive scaffoldings between group members were presented accordingly. This process induced students to develop the explanation of their models; the ideal practical epistemology was well-expressed and showed that cognitive collaboration among students occurs during mutually supportive engagement in a group modeling activity.

One important finding of this study is that the number of Level 4 cases was highly limited. Most cases were at Level 2 and Level 3. The possibility is that students were not provided explicit criteria for model evaluation though they were given chances to receive some training and guidance in model evaluation during the first two lessons. However, this indicates that a lack of in-depth evaluation exists with respect to models that provide explanations for mechanisms or processes of scientific phenomena, even though students have an epistemological awareness that the model should be validated. Therefore, it is necessary to develop strategies for model evaluation and justification, and to use them deliberately in group modeling practice.

For overcoming limited presence of Level 4, intervention by teachers will be needed when students do not realize the necessity of model evaluation or do not evaluate the explanatory nature of a model, such as processes or mechanisms of phenomena (Campbell *et al.*, 2012). Since students tend to construct models with simple descriptions of phenomena, the teacher should help them experience the epistemology concerning evaluation and metacognitive awareness. Indeed, students with metacognitive awareness do not passively accept others' models, but take a critical view and reflect on their own reasoning processes as well as those of others. In this study, metacognition occurred during the process of checking self-understanding and monitoring others' understanding, and this involved the revision of others' incorrect conceptions. Both self-monitoring and peer monitoring could only happen when students took a critical view of others' opinions. Hence, teachers should encourage students to play an active role as listeners in group modeling practice, clearly describing the necessity of evaluating the model and developing the explanatory power of the model to the phenomena.

In terms of practical epistemology, the process that students used to construct models was valuable because it is the same process that scientists use to generate knowledge. Students' practical epistemologies in a science classroom were explored and group modeling practice was identified as a valuable aspect of science instruction at school. Furthermore, the purpose and evaluation criteria of models need to be explicitly provided for students in order to expand the modeling lessons and manage these lessons more effectively, as higher epistemological understanding will lead to an in-depth modeling process (Sins *et al.*, 2009). Explicit epistemology lessons enable students to reflect on the nature of a given model and modeling (Schwarz & White, 2005). Unfortunately, there are many practical limitations: for example, teachers' lack of understanding of model-based teaching and learning, limited class hours for the teaching of a large curriculum, school record–oriented teaching and learning, and a lack of awareness of the importance of the nature of science. To overcome these challenges, there is an urgent need to change the perceptions of curriculum developers, education administrators, teachers, students, and parents.

For further areas of research, the effect of individual epistemological beliefs on cognitive interaction in a group should be investigated. A student's epistemological belief or learning approach can influence learning processes and outcomes (Songer & Linn, 1991). Thus, teachers needs to inquire into the beliefs of students before lessons are taught, and only engage in modeling practice after implementing proper actions. These endeavors would be helpful for understanding students' developmental practical epistemology in group modeling practice.

Ⅴ. Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group Modeling[3]

1. Introduction

Modeling—the process of constructing models—is one of the key processes for scientists in the development of scientific ideas. Scientists simplify complex phenomena through modeling and develop corresponding explanations (Giere, 1999; Gilbert *et al*., 2000; Morrison & Morgan, 1999; Nersessian, 1999). In recent years, modeling has received considerable attention as a useful educational method in the science classroom (Schwarz *et al*., 2009). A *model* is an explanatory system that represents objects or phenomena via discourses, writings, behaviors, and so on (Harrison & Treagust, 2000; Schwarz & White, 2005; Passmore & Stewart, 2002), while *modeling* is the process of constructing, examining, and evaluating models in order to make models that closely represent scientific concepts (Justi & Gilbert, 2002; Rea-Ramirez *et al*., 2008). Both models and modeling play an important role in developing students' understanding of certain phenomena or information by constructing and representing their mental models. Students generate and test their models through both empirical and thought

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[3] The study in chapter V was submitted in *Journal of Science Education and Technology*.

experiments in the science classroom that enable them to experience epistemic practices (Gilbert *et al*., 2000).

Rea-Ramirez *et al*. (2008) claimed that models can be elaborated through the participation of many people, which is the development process behind model generation, evaluation, and modification. This process enables students to engage in critical and reflective interactions with peers and accordingly triggers their cognitive participation (Mendonça & Justi, 2013). In particular, students who have higher cognitive abilities provide scaffolding to others during this process because of differences in the levels of students' actual and proximal development (Vygotsky, 1978). Some students do not just provide cognitive scaffolding; they also criticize and modify the opinions of others by engaging in critical monitoring (Oliveira & Sadler, 2008). In other words, students understand from participating in small-group activities that different individuals have different views and knowledge bases. Furthermore, they are able to construct higher quality models through cognitive collaborations with others than the models they create on their own.

In general, various group interactions occur depending on the member combinations, since each grouping of students will include individuals with different cognitive abilities, learning approaches, academic achievements, epistemological understandings, and affective attitudes toward science. Among those factors, learning approaches can be revealed through students' statements and can be a critical element in determining the success of group learning (Chin & Brown, 2000). *Learning approach* refers to the student's tendencies or attitudes as he or she solves learning tasks, and whether he or she attempts to understand associated concepts or relationships (Entwistle, 1981). In particular, students who use deep learning approaches tend to be motivated by *inner interest* or by an *intrinsic motivation* and they apply an in-depth strategy that connects their prior knowledge to the learning materials (Biggs, 1993). A process of cognitive reasoning with metacognition, which is one of the features found in deep learning approach, is critical for successful group modeling (Lee & Kim, 2013; Mendonça & Justi, 2013). Therefore, students using deep learning approaches may play an important role during the modeling process, because a student who has perfected a deep learning approach has generally developed a fairly strong metacognitive competency (Case & Gunstone, 2002).

Several researchers have stressed that students' learning approaches can have positive effects on individuals' conceptual changes and academic achievements (BouJaoude, 1992; Cavallo & Schafer, 1994; Stewart & Dale, 1989). However, little research has been conducted to explore how an individual student's learning approach affects group learning processes. Students who use deep learning approaches place emphasis on explanation and on the generation of spontaneous thinking, and try to evaluate and control their learning process through reflective thinking (Chin & Brown, 2000). Hence, small-group modeling would be influenced by cognitive interactions among students who have different learning approaches. In particular, students who adopt deep learning approaches would play an important role in the collaborative learning process.

This study assumes that learning approaches can be crucial both in individual learning and group learning processes, and focused on a group whose model was close to the target model and whose dialogic interaction patterns were shown. In the course of group modeling activities, it was also investigated that the group members' collaborative cognitive processes and positive cognitive participation ascertained how they were affected by the statements of deep learning approach (SD). The research questions were as follows:

1) What differences are there in the way the statements of the deep learning approach is expressed based on the features of each group modeling activity?
2) What effect do the statements of the deep learning approach have on cognitive collaboration and model development during the small group modeling process?

2. Methods

2.1. Participants

34 students in the eighth grade at K Girls' middle school in Incheon City, which is one of the metropolitan areas, participated in small-group modeling lessons. They were arranged in groups of three or four (nine groups), and to ensure heterogeneity within each group, members were selected according to the students' academic achievement. In addition, four students were selected from 34 students as subjects in this case study. The case study approach was suitable because it was intended to do an in-depth exploration of cognitive collaboration affected by the statement of deep approach (SD) during group modeling (Merriam, 1988). All models in nine groups were analyzed to select one focal group. As a result, four groups showed high-quality models that were similar to the target models. In particular, Group 6 was selected as the focal group because it consisted of two deep learners and two surface learners and because of the large amount of dialogic discourse patterns presented in this group. In dialogic discourse patterns, there can be more than one correct answer, and there are different points of view and chains of reasoning (Scott & Mortimer, 2003).

After selecting Group 6 as the tentative focus group, the students' changes that emerged during the learning process were analyzed, based on some materials in order to see whether Group 6 was suitable as a focal group. Consequently, changes in cognitive participation patterns and perceptions of confidence were found in the students of Group 6. For instance, the leader of the group was not always the same person but changed in the middle of the lesson. According to Bianchini (1997), the leader participates in the cognitive interaction actively and makes the most contributions to the group's learning. It was noteworthy that the leaders included both a high-achiever and a low-achiever; student C also served as a leader. Another change was found in the students' confidence. Low achievers showed less confidence in learning scientific concepts before the modeling-based lessons. However, all group members became confident in understanding the blood circulation concepts after taking the lessons, which was indicated in the responses to the post-survey questions concerning the understanding of concepts. Based on the above data, it was assumed there had been epistemic changes in science among the students in Group 6. It was also assumed these changes were caused by cognitive collaboration during group modeling, so their modeling processes were examined thoroughly.

The characteristics of the students in the focal group are shown in Table V-1. The students were classified into the categories of deep learner and surface learner based on the different science activity features that followed the approaches to learning science, as proposed by Chin and Brown (2000) (See Table V-3). By using this framework, Student A and C were revealed to be deep learners, while Students B and D were surface learners. Students A and C showed 23 and 21 SD respectively, which were about double the average SD of 12.2 frequencies. The learning approaches found in the analysis of the discourses showed consistency, which could be identified in the researchers' field notes, the student's worksheets, and the teacher's testimony. In terms of academic achievement, the mid-term exam and final exam scores were analyzed. Test scores are an absolute standard that is hard to indicate the improving and declining tendencies of students' academic performances. Thus, rankings in the whole class were demonstrated to compare the scores before and after taking the lessons.

The teacher who participated in this study had an eight-year history of teaching. She was working on a doctoral program in biology education at the graduate school. She had experience in studying small-group argumentation and was consistently committed to self-development by attending many kinds of training programs and meetings of science teachers.

Table V-1. Features of focal group students

Student	Learning approach	Mid-term exam(ranking)	Final-term exam(ranking)
A	Deep	6	6
B	Surface	16	11
C	Deep	25	26
D	Surface	35	32

The interview revealed that the teacher understood teaching and learning from a socio-constructive perspective. For example, she regarded herself as a helper that assisted students to explore by themselves and considered how to make students participate actively in group modeling. This perception was reflected in her lessons as well. She provided clues to help students construct models by themselves instead of giving correct answers directly, and she encouraged the students to participate actively in modeling. She was also helped the researchers revise the teaching and learning materials used in this study. She also assisted in selecting the focal group, by identifying the learning approaches of the students in the focal group and inferring their epistemic changes in the science lesson.

2.2. Task Characteristics of the Implemented Lessons

The researcher observed three modeling lessons about *blood circulation,* which were selected from the chapter, "Digestion and Circulation," in the science text book used in the eighth grade. Students may find it difficult to understand the concept of blood circulation because it is invisible and hard to experience. It also involves a wide range of concepts such as blood cells, oxygen, carbon dioxide, heart valves, heart, blood vessels, heart pressure, and so on (Buckley, 2000). Three 45-minute lessons were designed to encourage students' cognitive participation in the group modeling (see Table V-2). The tasks of each lesson were hands-on activities, which were developed to enable dialogical interactions among members to take place actively. In this way, the students were able to understand the circulation of the blood, maintain interest in the lessons, and eventually construct models cooperatively.

The first lesson consisted of siphon pump analogy modeling activity, which was designed to explain one-way water flow in the siphon pump. The analogy simplifies the target concept and gives a visual representation that supports students' understanding (Duit, 1991). As a simulation of the heart's pumping mechanism, the structures of the siphon pump and the heart are similar structures, and the mechanisms of water flow and blood flow are similar. Thus, this activity helped students to sustain their interest and have a better understanding about the concept. As students manipulated the siphon pump, they observed the one-way water flow by the opening and closing of the valves, which was influenced by the contraction and relaxation of the pump. This simulation encouraged students to reason spontaneously about single-direction water flow and construct corresponding explanatory models (Coll *et al*., 2005). Moreover, they reached a consensus on the group model through discussion and represented their model both orally and in writing.

The model created in the first lesson was intended to explain the direction of the water flow in the siphon pump, which is controlled by the opening and closing of the valves in the pipe, which is affected by the contraction and relaxation of the pump. The students were expected to produce the following models: When the pump is relaxed, the valve of the straight pipe opens, and water comes up through the pipe. While the pump is contracted, the valve of the straight pipe closes and water comes out of the pump through the opening of the valve in the curved pipe. Hence, the model in the first lesson is used as an analogy of the subsequent model for the second lesson, thus enabling students to understand the mechanism of one-way blood flow in the heart.

The second lesson is about the dissection of pigs' hearts. In this lesson, students observed the components of the heart, such as heart valves, atriums, ventricles, superior vena cava, pulmonary artery, and pulmonary veins. The analogy used in the first lesson was a simple structure compared to the heart, so it focuses only on certain aspects. Therefore, the students were asked to observe a real pig's heart in order to recognize differences between the object and the analogy (Grosslight *et al.*, 1991). At this time, because they could not see the real blood circulation in the heart, the students constructed explanatory models of blood circulation in the heart by recalling the siphon pump modeling activity. In this lesson, two kinds of explanatory models were produced by each group: one model explained blood flow without the semilunar valve and tricuspid valve in the right chamber; the other one showed one-way blood flow in the heart with heart pumping. Students' models were then represented both orally and in writing, as in the first lesson.

The models produced in the second lesson functioned as sub-models of the models used in the third lesson. These provided various data to construct comprehensive models regarding blood circulation. Students were expected to learn the following concepts: heart pumping is the power source of blood circulation; one-way blood flow is caused by the contraction and relaxation of the heart; oxygenated blood does not mix with deoxygenated blood because of the vessel wall which is in the middle of the heart; blood goes to each organ and muscle when it leaves the heart wall, which is the thickest and produces great pressure.

In the third lesson, each group drew a blood circulation diagram. Whereas six to eight minutes were allotted for modeling activity in the previous lessons, 35 minutes were provided in the third lesson, which occupied most of the lesson. During this lesson, the teacher served as a guide to first introduce the modeling activities and then help students to draw blood circulation models by interacting with their group members. Students recalled the models produced in previous lessons and constructed models through group discussions by applying prior knowledge in the third lesson. The group then drew a human figure on a large piece of paper and attached to it the pictures of the heart, brain, leg muscles, and lungs. They also drew systematic circulation and pulmonary circulation. They then marked oxygenated blood and deoxygenated blood using red and blue pens, respectively. Moreover, they wrote explanations about the gas exchanges of the vessels and organs. Consequently, the students' explanatory models were represented both orally and in blood circulation diagrams. Hence, the models produced in this lesson were expected to contain three concepts: systematic circulation, pulmonary circulation, and the gas exchanges in each organ and muscle.

Table V-2**.** Characteristic of the implemented lessons

	First Lesson	Second Lesson	Third Lesson
Instructional materials	Siphon pump as an analogy model	Pigs' hearts as an object	Pictures of organs and muscles, papers, and color pens for drawing
Modes of hands-on activity	Manipulation and observation of structure and process of one-way water flow	Dissection and observation of only structure	Drawing of blood circulation
Representational mode of model	Discourse, writing	Discourse, writing	Discourse, diagram
Target model	Explanation about the relationship between the structure of the pump and one-way water flow referring the pumping role	Explanation about the relationship between the structure of the heart and one-way blood flow referring the pumping role of the heart	Explanation about the circulatory system containing the systemic circulation, the pulmonary circulation, and the gas exchange in each organ and muscle
Purpose of modeling	Analogy model for understanding of sub-model	Sub-model as the evidence or data of constructing the final model	Final comprehensive model of circulatory system

2.3. Data Collection and Analysis

The three lessons on blood circulation were videotaped and audiotaped, and the discourse and gestures of the teacher and students were transcribed. The participants were asked to answer a pre-questionnaire before the lessons to check their perceptions of small-group activities and their roles in the group as well as to investigate their prior knowledge regarding blood flow in the heart. After the lessons, a post-questionnaire was distributed to determine whether students' perceptions changed or not. In addition to the perception of self-role in the group, collaboration with peer students, and the understanding of blood circulation concepts were also analyzed. In addition, students' worksheets, the groups' blood-circulation diagrams, and transcriptions were used to analyze the models and the modeling process. A variety of supplementary materials, such as student reports, research journals, questionnaires, and interviews with the teacher were also employed to gain in-depth understanding of the students' backgrounds.

The analysis of discourse was performed in four steps. In the first step, students' discourse episodes were divided with the sub-models. Eight episodes were selected from all three lessons: two episodes from the first lesson, two episodes from the second lesson, and four episodes from the third lesson. The author and the other person who was a PhD student conducted the SD coding, as shown in Table V-3, for the second step. This process was conducted independently, and an agreement between scorers was reached about some issues that emerged in further discussions. In the next step, the goals of argumentative discourse in the SD were distinguished: *sense-making, articulating*, and *persuading*. Lastly, the relationship between the SD and model development was identified by analyzing the model development process, which was based on the previous three steps.

The SD were classified into five categories and several subcategories based on the findings of Chin and Brown (2000). Table V-3 shows the characteristics of deep learners in learning science, and these are coded in order to analyze SD. According to Chin and Brown (2000), deep learners spontaneously present ideas and venture ideas for sustainable thinking in terms of *generating thinking*. With regard to the *nature of explanation*, they tend to focus on explaining mechanisms and obscure phenomena using mini-theories or models. They also request information about the mechanism and ask open and reflective questions that focus on resolving discrepancies in knowledge. In terms of *metacognitive activity*, using reflective thinking, they evaluate not only their own and others' ideas but also task process, standard and understanding. They also regulate actions by themselves. Finally, with regard to *approach to task,* they persist in following up on an idea with sustained interest before moving to another one.

Classification criteria of Chin and Brown (2000) was employed and elaborated the framework with the consensus of the author and the other person who was a PhD student to encode the students' SD. Denzin and Lincoln (2005) stressed that it is important for researchers reach an agreement on improving the validity of qualitative research. Following their opinions, a doctoral student majoring in science education, as well as the author, independently analyzed the students' performances during modeling practices (Table V-3), and scorers eventually reached a consensus on some disagreements.

Table V-4 showed an episode that represented the SD produced by Students A and C. This episode was extracted from Group 6's modeling in Lesson 1. The teacher asked the students to observe two kinds of siphon pump structures and then discuss differences between them in terms of water flow and structure. In Line 1, Student B asked, "which one has a valve?" and simply checked the difference of the structures. Later, Student A asked a question about the principle of one-way water flow (Line 8), which was coded as *request information of mechanism* (GT-a). And she ventured an idea by raising a question about the pump structure and the principle of water-flow (Lines 8), which was coded as *venture an idea* (GT-b). Although Student C gave simple answers (Line 7 and 9) at first, she later tried to give a logical explanation by linking water flow and valve movement (Line 11), which could be viewed as *focus on explanation of the mechanism* (NE-a).

Table V-3. Framework for classification of the statements of the deep learning approach

Statement category	Statement type	Coding*
Generating thinking	Present an idea	GT-a
	Venture an idea	GT-b
Nature of explanation	Focus on explanation of the mechanism	NE-a
	Explain with mini-theories or models	NE-b
Asking questions	Request information of mechanism	AQ-a
	Resolve discrepancies in knowledge	AQ-b
Metacognitive activity	Evaluate own idea	MA-a
	Evaluate other's idea	MA-b
	Evaluate task process	MA-c
	Reflect on standards	MA-d
	Reflect on positive understanding	MA-e
	Reflect on lack of understanding	MA-f
	Regulate action	MA-g
Approach to task	Persist in following up on an idea with some sustained interests before moving to another one	AT

* *Note* OO-alphabetic order indicates statement category-statement type order. GT = Generative thinking; NE = Nature of explanation; AQ = Asking questions; MA = Metacognitive activity; AT = Approach to task

Table V-4. Group 6's discourse analysis on Episode 1 from Lesson 1

	Speaker	Statement	coding
1	teacher	Observe the surface of both Pump A (normal pump) and B (valveless pump), open the top, and take a look at inside structure. Then try to explain how these two pumps lead to different results regarding water flow.	
2	B	Which one has the valve?	
3	A & C	(Pointing at the normal pump) This one.	
4	A	How does the valve make one-way water flow? Isn't it awesome?	AQ-a
5	B	You know, water gets through the cover.	
6	D	(stop saying when B starts saying)	
7	C	Water is not flowing backwards...	
8	A	(Pointing at valveless pump) Does water flows like this?	GT-b
9	C	Water just flows up and down in it (valveless pump).	
10	B	Because the valve blocks	
11	C	Water flows up and then flows in this way since it's blocking here.	NE-a
12	A	No, I'm asking whether water goes up from here. (indicating from the bottom to the top of the pipe)	AQ-a
13	C	It (valve) opens when water flows up like this.	
14	A	(Observing pumping at the same time)	
15	C	Look, it's flowing up.	

AQ-a = Request information of mechanism; GT-b = Venture an idea; NE-a = Focus on explanation of the mechanism

3. Results and Discussions

The objective of this study was to explore the cognitive collaboration and corresponding model development affected by deep learning approaches during group modeling of blood circulation. It was first examined how different SD were expressed in each lesson. Then a case study was conducted on Group 6, whose dialogical interactions were well presented, and their modeling process was analyzed thoroughly.

3.1. Patterns of Statements of the Deep Learning Approach Expression in Each Lesson

Learning approach provides a window on students' epistemologies in science (Chiou *et al*., 2013). It is also a constant learning orientation caused by motivation, values, attitude, prior knowledge, and learning concepts (Entwistle, 1981). Students show different learning approaches according to situational factors such as the nature of the task (Biggs, 1993). Three lessons were designed as hands-on activities to enable students to do small group modeling. Each lesson had an independent and coherent target model. That is, to construct a systemic model of blood circulation in the last lesson, all three lessons were developed with unique features. Because of this lesson design, it was assumed that the SD would be expressed differently in each lesson. Therefore, the SD frequencies were counted using the framework developed based by Chin and Brown (2000) (see Table V-5).

As shown in Table V-5, students' SD was classified into five categories: *generating thinking* (GT), *nature of explanation* (NE), *asking questions* (AQ), *metacognitive activity* (MA) and *approach to task* (AT). In addition, the frequencies were presented. Four hundred and sixteen SD were shown, and each lesson contained different amounts of each SD category. Compared to GT and MA, NE and AQ showed relatively lower frequencies, and AT was not found in this study. With regard to *approach to task,* it is true that deep learners tend to persist in following up on an idea with sustained interest before moving to another one (Chin & Brown, 2000). The feature *approach to task* could not be found in this case study. This was because students sustained to focus on one big idea such as blood circulation in these lessons.

Table V-5**.** Frequencies of statements of the deep learning approach in each lesson

Lesson	SD classification				
	GT	NE	AQ	MA	Total
1st lesson	16	15	8	13	52
2nd lesson	25	5	3	5	38
3rd lesson	147	30	16	133	326
Frequency	188	50	27	151	416

GT = Generating thinking; NE = Nature of explanation; AQ = Asking questions; MA = Metacognitive activity

The average SD frequencies in Lesson 1 and 2 were similar (6.5 times/ min, 6.3 times/min), whereas 9.3 times/min were found in the third lesson. In addition to the average SD frequencies, the dominant SD categories also differed in the three lessons. A relatively even distribution of SD categories was shown in the first lesson. The frequency of GT was dominant in the second lesson, and a relatively higher number of GT and MA were found in the third lesson. It was tried to find the reason for the differences in the modeling of relevant properties in each lesson (Table V-6).

First, the SD features showed a relatively even distribution of the SD categories in the first lesson. This was because of the characteristics of the evidence used as data for modeling. Students manipulated an analogy of the heart, the siphon pump, which enabled them to understand one-way blood flow in the heart. The siphon pump was used as an analogy because of its simple structure and visibility. Based on their observations, the students reasoned the causal relation among the valves, water flow, and the pump. In the first lesson, they needed little additional blood circulation-related knowledge, which was established by scientists, in order to construct their model. Thus, they showed spontaneous reasoning by expressing various SD, such as generating ideas, asking questions, giving explanations based on mechanism, and metacognition. For example, “how does this valve let the water flow one-direction?” (AQ-a), “if water flows towards the pump head, this valve can block the water flow downwards. This explain one-way water flow” (NE-a), and “why don’t you have a try at manipulating the pump? I don't fully understand that mechanism" (MA-f). During this process, students not only described the causal relationships among the valves, water flow, and the pump, they were also able to explain the mechanism regarding one-way water flow in the pump.

The category *generating thinking* (GT) was dominant in the second lesson. In particular, a significant number of *present an idea* (GT-a) was produced. For example, "blood may flow into 'B' direction and then stop flowing," "blood circulates the body so it may be never stop," and "If there are no heart valves, blood will stay in here". The target model in this lesson was to explain the blood flow mechanism in the heart, which has already been established by scientists. Students were asked to construct models by reasoning, based on their observations of the heart and their previous experience in the first and second lessons. However, they were not able to present various interpretations because they were hindered by the focus on authoritative knowledge about the complicated heart structure. This finding supported the results of Hug and McNeil (2008), which pointed out that it is difficult for students to have critical and active discussions in the context of existing scientific knowledge.

As in the second lesson, in the third lesson, the content of the target model was established by scientists. However, the *metacognitive activity* (MA) category showed a relatively high frequency compared to its frequency in the second lesson. For example, "we did not draw the pulmonary vein" (MA-c), "I think you don't have to draw here" (MA-b), and “now we confuse between arteries and veins” (MA-f). The number of concepts and their properties, which were used to construct the target model in this lesson, might have caused this result. The target models of the second lesson required explanations of causal relation in the level of a single organ. However, in the third lesson, the target model was a system model, which required the students to connect coherently sub-models, such as systemic circulation, pulmonary circulation, gas exchange in each organ and muscle, and so on. In other words, this lesson required comprehensive thinking skills. The students needed metacognitve competencies when they evaluated and modified the sub-models. Furthermore, making coherent connections among sub-models required evaluation and modification processes (Verhoeff *et al*., 2008). Consequently, the *metacognitive activity* (MA) category predominated in this lesson. The students constructed models by integrating information regarding structure, function/action, and causal mechanism related to blood circulation. They also made in-depth inferences during the processes of model evaluation, revision, and elaboration (Gobert & Pallant, 2004).

Table V-6. Modeling relevant properties in each lesson

	First Lesson	Second Lesson	Third Lesson
Data for modeling	Observation of the pump structure and one-way water flow	Experience from the first lesson, individual conceptual knowledge, and observation of the heart structure	Experience from the first and second lessons, and individual conceptual knowledge
Explanation in the target model	Water comes up through the pipe when the pump is relaxed and the valve of straight pipe opens , while water goes down when the pump is contracted and the valve of curved pipe opens	Blood flows from the left atrium to the left ventricle when the left ventricle is relaxed and the atrioventricular valve opens. Blood flows to aorta when ventricle is contracted and semilunar valve opens	The systemic circulation, the pulmonary circulation, and the gas exchange in each organ and muscle A circulatory system which coherently connects sub-models
Properties of conception in the target model	Causal relation	Causal relation	Causal relation and coherence in the system

3.2. Cognitive Collaboration and Model Development Influenced by Statements of the Deep Learning Approach

The analysis of discourses indicated the specific SD regarding the aims of argumentative discourse practice: *sense making, articulating*, and *persuading*. These kinds of SD enabled model generation, elaboration, evaluation, and modification. They also helped to enhance the understanding and participation of the group members. Hence, based on SD's functions, cognitive collaboration was categorized into cognitive scaffolding and critical monitoring.

3.2.1. Cognitive scaffolding

According to Vygotsky (1978), the distance between the actual developmental level and the potential developmental level is the *zone of proximal development* (ZPD). A student can reach the ZPD with the scaffolding provided by an adult guide or by peers that are more capable. Scaffolding enhances the understanding of students who have not yet reached the potential developmental level and enables them to develop concepts (Hogan & Pressly, 1997). In this study, as scaffolding, cognitive collaboration ensured high-quality learning results when the group members had different levels of cognitive abilities (Wood *et al*., 1976). The deep learners in Group 6 produced *nature of explanation* (NE) and *asking questions* (AQ), which involved *sense making*, and they provided cognitive scaffolding to their peers in the group. Consequently, cognitive chain reactions, such as model generation and elaboration, occurred.

1) Model generation phase

The model-generation phase required creative and evaluative thinking skills. Students collected data to generate the best model to explain the phenomenon. At this time, knowledge that could be used as evidence for constructing models was obtained through experiments or a literature review, or it might have already existed as prior knowledge (Justi & Gilbert, 2002). After gathering data, the students needed particular thinking skills to select the appropriate model components. Even though the students used the same process for collecting data, the amount of data that was used in modeling differed according to their knowledge bases, learning strategies, and thinking skills. Hence, the critical element was the deep learning approaches to think of the components of the model deeply, with the goal of making sense of the target phenomenon.

With regard to the modeling process of Group 6, the first model in the third lesson was generated when a high-achieving student articulated the statements for sense-making about the principle of blood circulation, as shown in Table V-7 and Table V-8. Two episodes concerning systemic circulation were selected from the third lesson: one was about the heart-hand muscle circuit, and the other one was about the heart-brain circuit. Like other groups, students in Group 6 had a difficulty in starting to draw the diagram in the beginning of the lesson (Table V-7). At that time, a high-achieving Student A said, “Let’s draw it just like spreading through the whole body,” which connoted that the heart is driving force of blood circulation (Line 2). Her attempt showed that she applied the data obtained from previous lessons to the new modeling activity. Sense-making of the phenomena was then articulated through the *focus on explanation of the mechanism* (NE-a), and the sub-modeling began. Student C then added the aorta that is located after the heart in the pathway, thus elaborating their model (Line 5).

During the process of sub-modeling the heart-brain circulation, Student A again emphasized the pumping role of the heart (Table V-8). She raised questions about the concept of “blood circulation initiates from the brain” in the group model, which contradicted her perception that “blood circulation initiates from the heart,” which was gained in the previous lessons (Line 1). This SD was involved in *resolve discrepancies in knowledge* (AQ-b) and triggered the generation of the heart-brain model. In addition, the model was developed because Student C articulated the current model (Line 2, 4, and 6) and encouraged others to be involved in the model evaluation.

Table V-7. Episode 1 in Lesson 3 (Systemic circulation: Heart-hand muscle circuit)

	Speaker	Statement	Coding	Model development
1	D	How should we draw?		
2	A	Let's draw it just like spreading the whole body	NE-a	<u>Model generation</u> [Heart pumping is the driving power of blood circulation]
3	D	Here and here (pointing with a pen)		
4	A	Draw a line from here to here		
5	C	I will draw the artery… comes out of the aorta	GT-a	<u>Model elaboration</u> [Pathway of the heart-hand circuit: heart → aorta → (hand muscle)]

NE-a = Focus on explanation of the mechanism; GT-a = Present an idea

Table V-8**.** Episode 2 in Lesson 3 (Systemic circulation: Heart-brain circuit)

	Speaker	Statement	Coding	Model development
1	A	It's not the brain. Blood doesn't spread from the brain. Where does blood come out? Now?	AQ-b	Model generation [Heart-brain blood circulation initiates from the heart]
2	C	This is the aorta, that's the superior vena cava.		
3	D	It's strange here.		
4	C	Hey, isn't it thin here?		
5	D	It's enough to draw a thick line there.		
6	C	There are only two vessels connecting here.	MA-c	Model evaluation at superficial component level [Pointing out the issue drawing only two capillary vessels around the brain]

AQ-b = Resolve discrepancies in knowledge; MA-c = Evaluate task process

Two kinds of misconceptions were found in other groups. One was "systemic circulation initiates from the heart and goes through each organ and muscle in turns and then flows back to the heart." The other one was "the oxygenated blood flows from the lung to each organ and muscle." It should be noted that Group 6's models did not exhibit these errors. They had a clear perception of the pumping role of the pump. Furthermore, they perceived that the heart-hand muscle circuit and the heart-brain circuit had independent pathways, and they understood the lungs could not pump. Consequently, their model had a branched systemic circulation pathway, and they showed the correct flow of the oxygenated blood to each organ.

Moreover, in the scaffolding provided by Student A, she articulated the pumping role of the heart and showed how to generate the model, which enabled others to generate sub-models. As student with a high academic achievement explained the basic principle of blood circulation and provided the exploring question, the other group members could structuralize their idea about the driving power of blood circulation. Based on the findings of Kim and Hannafin (2011), the scaffolding in these episodes can be categorized as *conceptual scaffolding*. Student C not only elaborated on and evaluated the existing models but also generated a new sub-model.

This occurred in Episode 3, which was selected from the third lesson (Table V-9). Student C generated and elaborated the pulmonary model through the SD, *focus on explanation of the mechanism* (NE-a) (Line 1). She emphasized that the heart was the driving force of pulmonary circulation, saying "The pulmonary artery comes out of the heart." Student C's SD mentioned the pathway of pulmonary circulation, and the model was then elaborated in a series of cognitive participations. In addition, Student D articulated *request information of mechanism* (AQ) by asking questions about the place of gas exchange (Line 2). Student C then articulated the gas exchange in the lungs (Line 3) and drew the oxygenated blood to elaborate the model (Line 5).

Table V-9. Episode 4 in Lesson 3 (Pulmonary circulation)

	Speaker	Statement	Coding	Model development
1	C	The pulmonary arteries are blue in color because the pulmonary arteries go out from the heart. Pulmonary arteries, pulmonary capillaries, pulmonary veins, left atrium and left ventricle.	NE-a	Model generation [Pulmonary circulation initiates from the heart] Model elaboration [pathway of the pulmonary circulation: Heart→ the pulmonary artery→ the pulmonary capillary→ the pulmonary vein→ heart]
2	D	Where was the blood purified?	AQ-a	Stimulation of model elaboration
3	C	(pointing out) From here.		Model elaboration [Place of gas exchange (lungs)]
4	D	And then it flows into here.		
5	C	These are the pulmonary veins because the veins go into the heart, we should draw the veins, the left atrium, the left ventricle and left ventricle.	NE-a	Model elaboration [Marking the oxygenated blood in the pulmonary vein, the left atrium, the left ventricle]

AQ-a = Request information of mechanism; NE-a = Focus on explanation of the mechanism

2) Model elaboration phase

In the science classroom, the questions generated by the students lead to productive discussions and the meaningful construction of knowledge. There are two kinds of in-depth questions: r*equest information of mechanism* (AQ-a) and *resolve discrepancies in knowledge* (AQ-b). Both involve *sense-making* (Berland & Reiser, 2011). Their in-depth questions enable them to connect the new concept to the current understanding and participate in group interaction during the process of resolving cognitive discrepancies (Chin & Chia, 2004). In the case of Group 6, *focus on explanation of the mechanism* (NE-a) triggered SD and provided cognitive scaffoldings to other students. Thus, all students were able to participate in the reasoning process, and most eventually made contributions to the elaboration of the group model.

Episode 2 in the first lesson showed this process (Table V-10). The students tried to construct an explanatory model regarding the inner structure of the siphon pump by applying the one-way water flow mechanism. Student A proposed the initial model, saying “water flows upwards in the straight pipe when the pump is contracted,” and asked a question relating to *request information of mechanism* (AQ-a), which stimulated the elaboration of the model (Line 1). Some chains of reasoning emerged because of this SD. Moreover, many students participated in the model elaboration process by referring to some SD. Kim and Hannafin

(2011) defined metacognitive scaffolding as providing help related to planning, evaluating, and reflecting in order to regulate the learning process. As the questions enlighten students about the necessity for elaborating on the group models, these SD were regarded as metacognitive scaffolding.

Student B answered Student A's question by expressing *present an idea* (GT-a), which elaborated the model by adding the idea that the valve in the straight pipe influenced the water flow (Line 2). Student A then presented a specific model showing that water flow was affected by the movement the valve (Line 3), and she also asked an in-depth question related to the mechanism of the water flow and the valve movement. This stimulated the model elaboration, and Student C explained the mechanism (Line 4). Student A asked for new information about whether or not the pump head could save water (Line 6). Students B, C, and D understood that "water in the pump head flows to the curved pipe when the pump is contracted" and they gave corresponding answers (Lines 7, 8, and 9). They contributed to the development of the group model because they added the content, "the valve movements enable one-way water flow since water can be saved because of the valve movement." Moreover, Student C reinforced the explanatory model (Line 11), and the questions raised by Student C were solved. The group model was completed because of the cognitive interactions in the group, and the students were able to understand the mechanism of the target model.

The students' in-depth questions tended to ask "how" or "why" instead of “what.” Hence, the elaboration of the model was stimulated by requiring *sense-making* of the phenomena. The answers to these kinds of questions cannot simply describe the phenomenon; they also need to explain the mechanism that provided them with cognitive scaffolding. In addition to scaffolding, cognitive participation was also found in Students B and D. Although they could not answer Student A’s question in the beginning (Line 1 and 4), they were later able to understand the mechanism of one-way water flow in the pump because Student C’s SD focus on the mechanism (Line 5) functioned as cognitive scaffolding. This finding showed that they participated in the model elaboration process by adding additional explanations of the mechanism (Lines 7, 8, and 9).

Table V-10. Episode 2 in Lesson 1 (One-way water flow in the siphon pump)

	Speaker	Statement	Coding	Model development
1	A	(Operating the pump) water flows upwards by pushing it (pump) and put it back…no...How does it work?	AQ-a	Stimulation of model elaboration [water flows up through the straight pipe when the pump is contracted]
2	B	This is because the valves hit and push up the water. Right?	GT-a	Model elaboration [when the pump is contacted, the valve in straight pipe drives water upwards]
3	A	No, it (the valve of straight pipe) closes when you push it, but it opens when it turns back.	NE-a	Model elaboration [Once the pump is contracted, the valve in the straight pipe closes and vice versa.
4		Why does it work like this?	AQ-b	Stimulation of model elaboration
5	C	I think that water in here flows to here (curved pipe) when you push it (pump head). If you put away your hand, water flows upwards and saves in here (pump head).	NE-a	Model elaboration [Water flows up through the curved pipe when the pump is contacted. Once the pump is relaxed, water flows upwards and be saved in the pump head.]
6	A	Can water be saved in the pump head?		

(*Continued*)

Table V-10.
(*Continued*)

	Speaker	Statement	Coding	Model development
7	C	Here (pump head) the water is.	GT-a	Model elaboration
8	B	So the saving water flows down like this.	GT-a	[when the pump is contracted, water in the pump head flows to the curved pipe]
9	D	That's why water drops from the cover.	GT-a	
10	A	Isn't it because it (the valve in the curved pipe) closes and blocks water going downwards?	NE-a	
11	C	So saving water in here drains out when pushing the pump. That's why there is no water inside. Once it sucks again, water turns up again.	NE-a	Model reinforcement
12	A	So (water) can't drain out when the valve (in the straight pipe) closes.		
13	C	Yes.		
14	A	I see. Pushing it drives water out	.	
15	D	That's how water is saved in the pump.		

AQ-a = Request information of mechanism; AQ-b = Resolve discrepancies in knowledge; GT-a = Present an idea; NE-a = Focus on explanation of the mechanism

3.2.2. Critical Monitoring

1) Model evaluation and modification phase

Critical monitoring involves checking one's own or others' understandings, which is used by deep learners, and is a critical characteristic of scientific activity (Chin & Brown, 2000). It can play an important role when students are engaged in an activity that requires them to work collaboratively in explaining a phenomenon (Oliveira & Sadler, 2008). Because the students' knowledge bases varied, the justifications for different assertions and agreement or disagreement on these opinions emerged (Böttcher & Meisert, 2011). This process is important for monitoring because it demands *sense-making* of the explanations discussed on a social plane. It is also the goal of argumentative discourse in terms of *persuading*. It can also trigger criticism and evaluation (Berland & Resier, 2011). During this process, the quality of models and reasoning can be enhanced when students try to persuade others using evidence and to justify their own models (Lee & Kim, 2013).

In Group 6, critical monitoring took place mainly in the third lesson, which involved the construction of final comprehensive model of the circulatory system. Their critical monitoring was not a one-time event, but it was produced repeatedly and influenced by interactions within the group. This finding showed that students actively participated in argumentative practice that generated, evaluated, and modified the model repeatedly.

Episode 4 in the third lesson is shown in Table V-11. It demonstrated the process of modeling on systemic circulation. The heart-leg muscle circuit and the cyclic process involving model generation, evaluation, and modification (GEM cycle) were well shown. Student A produced the SD-*resolve discrepancies in knowledge* (AQ-b), and she raised problems in the diagrams that they had drawn so far (Line 1). Her monitoring question seemed to stimulate the evaluation of the existing model, but other students did not agree with A's opinions (Lines 2 and 3). Hence, Student A qualified her previous statement in detail, and she evaluated the model as follows: "There is no superior vena cava which connects the leg muscle and the heart" (Line 4). Although she raised the issue, others did not seem to solve the problem. She then showed *evaluate own idea* (MA-a), by applying the concept of branched systemic circulation to the model: "Leg muscle and brain circuit have different veins" (Line 9). Her attempt of modifying the model through suggesting the warrant enhanced the understanding and participation of the other group members in reasoning. This finding was detected in the following SD: Students C and D evaluated the modified model by producing *evaluate other's idea* (MA-b) and *request information of mechanism* (AQ-a), respectively (Lines 10 and 11).

To justify her criticism and evaluation, Student A reinforced and articulated the previous model (Line 12). Through this process, Student C understand Students A's model, and then criticized that "It cannot be painted in red because the deoxygenated blood flows in the vein," thus showing *evaluate other's idea* (MA-b) (Line 15). This evaluation did not focus on the mechanism of A's model. However, her statement can be viewed as *reflect on lack of understanding* (MA-f) because the issue was caused by the detailed capillaries, which made distinguishing the vessels difficult (Line 16). This provided them the opportunity to reflect on modeling practice and enabled them to construct a better model.

The findings showed that critical monitoring enabled students to evaluate and modify the model. Cognitive scaffolding and other monitoring also emerged accordingly. Critical monitoring also involves the goals of argumentative discourse, such as *persuading* and *sense-making*, and students showed active participation in the epistemic practice of science learning. Several researchers pointed out that modeling practice is based on argumentation (Böttcher & Meisert, 2011; Mendonça & Justi, 2013; Passmore & Svoboda, 2012). These results again supported their assertions. The group model was developed by repeating the evaluation and modification of the model through argumentative interactions. The cognitive participation and understanding of group members were enhanced accordingly.

Table V-11. Episode 4 in Lesson 3 (Systemic circulation: Heart-leg muscle circuit)

	Speaker	Statement	Coding	Model development
1	A	Isn't here a little weird?	AQ-b	<u>Stimulation of Model evaluation</u>
2	D	What?		
3	C	It's correct.		
4	A	If we paint here, the aorta comes from the heart but no vessel goes into here. Isn't it?	AQ-b	<u>Model evaluation</u> [There is no superior vena cava that connects the leg muscle and the heart.]
5	C	That's the aorta		
6	A	How to draw here?		
7	D	Just draw.		
8	C	Continue drawing.		
9	A	You should've painted. These two lines should go both directions like this.	MA-a	<u>Model modification</u> [Branched systemic circulation concept: Leg muscle and brain circuit have different veins]
10	D	The lines are too thick if you draw so.	MA-b	<u>Model evaluation</u> at superficial component level
11	C	No, why does it come together? Why did you draw like this?	AQ-a	<u>Model evaluation</u>
12	A	See. It flows out in two paths like this.	NE-a	<u>Model reinforcement</u> [Branched systemic circulation concept]
13	C	Ok.		
14	A	Where can it return?		

(*Continued*)

Table V-11.
(*Continued*)

Speaker		Statement	Coding	Model development
15	C	(Impatiently) Why did you paint here regardless of here? It is the aorta and this is the superior vena cava. But it looks weird if you paint red here.	MA-b	<u>Model evaluation</u> [It cannot be painted in red because deoxygenated blood flows in the vein.]
16		Our diagram draws so in details. This is the mistake.	MA-f	[It is hard to distinguish vessels because of the detailed capillaries.]
17	A	(Removing with a correction tape) I'm messed up.		
18	D	(Drawing with a blue pen)		
19	A	(Say to D who's drawing with a pen) It should go to the aorta in this way. It shouldn't be removed.	MA-b	<u>Model reinforcement</u> [Branched systemic circulation concept]

AQ-a = Request information of mechanism; AQ-b = Resolve discrepancies in knowledge; AE-a = Focus on explanation of the mechanism; MA-a = Evaluate own idea; MA-b = Evaluate other's idea; MA-f = Reflect on lack of understanding

4. Conclusion

In a sociocultural perspective, students play important roles when they are engaged in a successful process of meaning construction (Hogan *et al*., 2000; Richmond & Striley, 1996). In this study, students provided cognitive collaboration during group modeling processes. These were explored, and their roles focusing on the SD were analyzed. The findings indicated that individual SD influenced collaborative modeling through the deep reasoning process. This study may have educational implications for authentic group modeling lessons.

The first purpose of this study was to examine the differences in SD expression in each lesson. The final target model was the explanation of a circulatory system. To reach this goal, in the first and second lessons, students were asked to do hands-on activities that enabled them to acquire conceptual and empirical knowledge. During these lessons, they needed deep thinking skills because they were engaged in student-centered group modeling. The dominant SD categories found in each lesson varied because of the different properties relevant to the modeling. In the first lesson, a relatively even distribution of SD was found. This was because this lesson was an analogy hands-on activity and did not require prior conceptual knowledge, and spontaneous reasoning emerged accordingly. In the second lesson, pigs' hearts were dissected, and the students observed their structure. The students then made inferences about the mechanism of the blood flow in the heart based on this observation and the experience in the first lesson.

Students were likely to show the SD, *present an idea* (GT-a), because they focused on authoritative knowledge regarding the complicated structure of the heart, and they did not demonstrate various ideas and opinions. In the third lesson, students employed the conceptual and empirical knowledge obtained from the previous lessons and made coherent connections with them. Hence, several metacognitive SD emerged because they needed to use comprehensive thinking. In order to stimulate students' diverse SD expression, hands-on activities that can induce students' spontaneous reasoning need to be considered in the modeling-based lessons. In addition, metacognitive thinking skills can be used in the science lesson, which has more comprehensive target models.

The second purpose was to explore the effects of the SD on cognitive collaboration and model development. Cognitive collaboration involved cognitive scaffolding and critical monitoring: cognitive scaffolding contributed to the generation and elaboration of the model, whereas critical monitoring contributed to the evaluation and modification of the model. The generation of the model required the understanding of basic principles. It was therefore triggered by the high-achieving students' SD, *explanation of mechanism* (NE-a), which functioned as conceptual scaffolding to the low-achieving students who generated the new sub-models. During the model elaboration, some students provided metacognitive scaffolding that required sense-making when others *requested information about the mechanism*

(AQ-a), which triggered *explanations of the mechanism* (NE-a). The model evaluation process occurred when students showed critical monitoring, which was triggered by the SD, *asking questions* (AQ) and *metacognitive activity* (MA). These SD emerged to enhance the explanatory power of the model and was effective in persuading others and justifying the models.

The case study focused on a group of four students. A limitation of this study is that findings were based on the observation of specific small-group modeling situated in a specific time and place, so that the results cannot be generalized to all cases. However, the findings of the study of 'Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling' indicated that the SD generated a deep reasoning process. The statements of deep learners, which included asking, evaluating, clarifying, and elaborating, reflected the goals of argumentative discourse, such as *sense-making*, *articulating*, and *persuading*. Moreover, their progressive interactions enhanced their cognitive participation and understanding. Hence, the group model was developed through the processes of generation, elaboration, evaluation, and modification.

Three lessons were designed to support students' collaborative modeling. These consisted of hands-on activities that emphasized the significance of the instructional material. Although the planned modeling inquiries enabled the students to sustain interest and stimulate cognitive collaboration, not all groups showed cognitive collaboration. The science classroom of technology-based small-group modeling in which technology would be used as instructional material can be recommended. The use of technology would benefit deep learners by supporting their cognitive collaboration with others during the process of group modeling. It would also benefit cognitive collaboration in the following three ways.

First, technology could be very useful when students are engaged in modeling tasks that involve phenomena that cannot be experienced and observed. Technology could demonstrate "tricky" phenomena, thereby assisting students' understanding. In particular, students tend to have difficulty in understand many biological systems, such as the respiratory system, circulatory system, and ecosystem (Verhoeff *et al.*, 2008). Modeling related to these topics requires them to connect model components coherently in order to construct a model. Students are also unsure about how to start the modeling process (Buckley, 2000). Technology could enrich their conceptual knowledge through visual demonstration, thus helping them to solve these problems and enabling students' cognitive interactions. A study carried out by Berland and Reiser (2011) showed the efficiency of technology. In their study, students were engaged in an argumentation lesson regarding constructing and explaining applications. Simulations of the organism's interactions in the food web were shown in the computer. The visual aid of simulation helped students understand the phenomenon, which enabled students' discourses concerning knowledge construction.

Second, technology could be used as evidence in the reasoning process of modeling (Svoboda & Passmore, 2013). The results of the study showed that modeling practice involved model generation, elaboration, evaluation, and modification through argumentative discourses. The model became more sophisticated through a process of criticizing and justifying. These processes are the essential components of argumentation needed as evidence. In this study, some students noticed that the experience obtained from the previous two lessons could be used as evidence in the third lesson, but other students did not. This might have been caused by the intervals between the lessons in which students could have forgotten what they had learned in the previous lessons. This problem could be prevented by making video clips of the lessons or related concepts so that students could review the content at any time. In addition, a simulation of blood circulation could be employed as evidence to evaluate the validity of models.

Finally, technology could improve the environment in which students collaboratively communicate during the process of small-group modeling (Bell & Linn, 2000; Pata & Sarapuu, 2006). It was noticed that the SD gave a benefit to cognitive collaboration, but it could not be dismissed that quiet deep learners were included in the group. In fact, the SD was found in some groups, but some deep learners seemed to be reticent because of the group atmosphere. In this regard, social tendencies should also be taken into account in order to promote participation on the social plane. This issue could be resolved by using online tools, such as chat rooms or BBS because these tools do not demand for face-to-face discourse. In addition to quiet deep learners, students who take a long time to think would be able to benefit from these online tools.

The SD stimulated cognitive reasoning during the group modeling triggered model development. It should be noted however that not all SD led to reasoning processes and model development. Further research should explore the interactions that emerge between the lesson context and the individual approach to learning, as well as the effects of these interactions on cognitive collaboration. In addition, longitudinal research concerning the effects of group modeling lessons on students' learning approaches could aim to identify whether students apply the same methods in others discipline or not and to explore the ripple effects on others. These studies would support students' epistemic experience of modeling in an environment that appropriately considers individual features, such as the motivation and strategies used in approaches to learning science.

Ⅵ. CONCLUSION AND IMPLICATION

1. Conclusion

This dissertation investigated middle school students' cognitive collaboration in group modeling on blood circulation. The study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling' identified the patterns of model development and the factors that led to differences in reasoning among several groups developing one-way circulation models. The patterns of model development, such as the *unchanged*, the *added*, and the *elaborated*, were influenced by critical revision, which was a kind of critical and reflective participation in group interaction. Among these three patterns, the *elaborated* pattern was the one that led to the sophisticated model development. The high-level reasoning process necessary for strong scientific argument (because it has diverse elements of argumentation) was found in the *elaborated* pattern. The analogy model activity helped students to engage in group reasoning spontaneously, and cognitive conflicts within groups enabled students to justify, evaluate, and modify their models. Accordingly, the initial model was elaborated and finally reached the target model.

Based on the finding of the study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling' that shaped the critical role of evaluation for model development, the study of ‘Epistemological Features and Model Qualities Depending on the Model Evaluation Levels’ found epistemological features and model qualities depending on the model evaluation levels and identified the epistemological features in terms of the cognitive reasoning process for understanding the context of Level 4 model evaluation. The students’ epistemological features and model qualities differed according to the model evaluation levels, which ranged from Level 1 to 4. At Levels 1, students did not think about the necessity of change and did not justify the models using scientific reasoning. At Level 2, students justified the models not through the use of scientific reasoning, but through the use of authoritative sources, which they regarded as possessing absolute truth. That is, the students at Level 2 showed the absolutist epistemology. At Level 3, Students justified the model with evaluative epistemology, but their justifications were based on simple comparison of the superficial aspects of the model. Thus, their models became more elaborate on the superficial level. At Level 4, however, students showed an evaluative epistemology and understood the explanatory nature of models. Accordingly, the group model ultimately became more sophisticated because of the justification that occurred during the process of reasoning. Level 4 model evaluation was triggered when students attempted to use metacognitive monitoring to examine their own or others’ understanding.

In high-level model evaluation, reasoning processes through cognitive collaboration were well-expressed by monitoring one’s own or others' understanding. Based on this finding of the study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels', the study of 'Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling' explored the relationship between the statements of the deep learning approach and the features of each group modeling activity, and identified cognitive collaboration during group modeling processes focusing on the statements of deep learning approach. The SD expressions in each lesson were different due to the modeling-relevant properties. If the data for modeling was experience of manipulating an analogy and barely needed for authoritative knowledge, diverse SD categories were expressed in the lesson. In addition, several metacognitive SD were dominant in the modeling activity in which the target model had comprehensive concepts. This was because the students needed to use comprehensive thinking skills. Another finding was that individual SD influenced collaborative modeling through the deep reasoning process. Cognitive collaboration was categorized into cognitive scaffolding and critical monitoring. Cognitive scaffolding could contribute to the generation and elaboration of the models. The high-achieving students' SD such as *explanation of mechanism*, functioned as conceptual scaffolding to the low-achieving students in the model generation phase. The students' SD such as *request information about the mechanism*, provided metacognitive scaffolding to others, and stimulated the chains of reasoning for the model elaboration. Critical monitoring was triggered by the SD, such as *asking questions* and *metacognitive activity*. These SD emerged to enhance the explanatory power of the model and was effective in persuading others and justifying the models.

2. Implication

The findings of this study a range of pedagogical implication for the science classroom. First, the participants could experience epistemic practice in science by participating in model generation, evaluation, and modification for constructing the final target model. Though students, in the previous studies, accepted models as illustrations in text or miniatures of real objects passively in school, some participants in this study performed modeling by building knowledge actively like scientists. Therefore, group modeling-based lessons need to be extended to other middle schools.

Second, although all participants were part of the same instructional context, they did not show the same modeling process. In the study of 'Patterns of Group Model Development and Factors Influencing Reasoning Process in Collaborative Modeling', some groups showed the *unchanged* and the *added* pattern of model development and lacked critical monitoring while group modeling. The *elaborated* pattern, which had critical monitoring in modeling, showed high-level reasoning. In order to encourage critical monitoring, it is important to form a permissive atmosphere within groups for active interaction during group modeling.

Third, the deep reasoning process was revealed mainly in model evaluation phase during the GEM cycle. In the study of 'Epistemological Features and Model Qualities Depending on the Model Evaluation Levels', the students showed diverse performances on their evaluations by using different criteria of evaluation, and, accordingly, they demonstrated the different epistemological features. In the high-level of model evaluation, the explanatory power of models was used for the criteria and justification based on evidence and rebuttals were expressed. Monitoring one's own or others' understanding was critical for showing these epistemological features. Therefore, it is necessary not only to encourage active participation but also to enhance epistemic understanding of model evaluation criteria.

Fourth, cognitive collaboration in group modeling was investigated in relation to individual student's learning approaches in the study of 'Expression of Statements of the Deep Learning Approach and Cognitive Collaboration in Group modeling'. The statements of the deep learning approach were attributed not only to individual learning but also to collaborative group learning by facilitating deep thought or chain of cognitive reasoning. Therefore, the individual learning approach as well as academic achievement needs to be considered when organizing group members, and educational intervention is needed for students who have surface learning approaches to participate in deep reasoning processes.

Meanwhile, this dissertation recommends the following further researches. First, this study investigated the interaction within groups minimizing teachers' intervention. If all group members engaged actively in the interaction, their cognitive participation was well-expressed in the group. In the opposite case, however, group modeling did not progress. Teachers' intervention may be important in this situation that students passively participate in verbal interaction, because a teacher can encourage students' cognitive collaboration or help students maintain a chain of reasoning. Therefore, further study is needed to identify teachers' roles in group modeling.

Second, this study assumed that each student's learning approach and academic achievement served an important role in cognitive collaboration while group modeling. Even though the member composition of some groups was similar to the successful group, the cognitive reasoning process was not found. This was because group atmosphere could hinder group interaction which is important for group modeling. Therefore, further study is needed to investigate how group culture or group norms influence to group modeling from a sociocultural perspective.

Third, this study identified the possibility that an individual student's cognitive characteristics could influence the group modeling process. However, it did not investigate the relationship between students' affective features (e.g., situational interest, orientation, learning efficiency, and so on), group modeling practice, and the changes in an individual student's cognitive features during group modeling-based lessons. Therefore, further study is needed to consider students' affective features in the research design and to explore how the affective features harmonize other cognitive factors and influence the group modeling process as well as why changes in these features affect the group modeling process.

Fourth, this study focused the instructional materials, and provided specially designed hands-on activities to students for supporting collaborative modeling. These activities maintained students' interest and helped students understand phenomena as the modeling target. Although these activities supported cognitive collaboration, this type of collaboration was not found in all groups. Further study of technology-based small-group modeling in which technology is used as an instructional material, is recommended in the science classroom. Technology will help students understand phenomena that cannot be experienced and observed through visual demonstration. In addition, it could be used as evidence in the reasoning process of modeling, and support students who have difficulty in face-to-face discourse.

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Appendix

Appendix 1. Pre-questionnaire

안녕하세요. 서울대학교 생물교육과 생물교수학습연구실입니다. 본 설문은 중학교 학생들이 가지고 있는 소그룹 활동에 대한 인식과 앞으로 배우게 될 개념에 대한 질문으로 이루어져 있습니다. 여러분의 응답은 소그룹 활동에 대한 연구에 도움이 될 것이며, 여러분이 작성한 설문지는 절대적으로 비밀이 보장되며, 외부로 노출되지 않습니다. 최대한 솔직하게 작성해주시길 바라며 설문에 응해주셔서 감사합니다. 서울대학교 생물교육과 생물교수학습연구실 02-880-7769

( )중학교 ( )학년 ( )반 ( )번 (남/여)	이름( )

소집단 활동에 대한 인식

1. 소집단 활동(조별활동, 모듬활동)하면 무엇이 떠오르나요?

2. 지금까지 소집단 활동(조별활동, 모듬활동)에 나는 적극적으로 참여했다고 생각합니까?
① 매우 그렇다. ② 그렇다. ③ 보통이다.
④ 그렇지 않다. ⑤ 매우 그렇지 않다.

3-(1) 전체 학급이 선생님 말씀을 동시에 듣는 수업보다 소집단 활동(모듬활동)을 좋아합니까?
① 그렇다 ② 아니다

(2) 이유는 무엇입니까?

4-(1) 소집단 활동(조별활동)이 필요하다고 생각합니까?
① 그렇다 ② 아니다

(2) 이유는 무엇입니까?

5-(1) 과학수업에서 소집단 활동(조별활동)은 어느 정도 차지한다고 생각합니까?

① 20%이내 ② 20-40% ③ 40-60%

④ 60-80% ⑤ 80%이상

(2) 앞으로 과학수업에서 소집단 활동(조별활동)은 어느 정도였으면 좋을까요?

① 20%이내 ② 20-40% ③ 40-60%

④ 60-80% ⑤ 80%이상

7. 지금까지 우리 조(모둠)의 구성원은 어떻게 이루어졌습니까?

① 같은 성별로만 이루어져있었다.

② 다른 성별도 섞여 있었다.

8-(1) 소집단 활동(조별활동)이 잘 되려면 조(모둠)구성을 어떻게 하는 것이 좋을까요?

① 같은 성별로만 이루어져야 한다.

② 다른 성별도 섞여있어야 한다.

(2) 그 이유는 무엇입니까?

9-(1) 소집단 활동(조별활동)이 잘 되려면 우리 조(모둠)에 어떤 친구가 포함되면 좋을까요?

① 공부 잘하는 친구

② 말을 잘 하는 친구

③ 나와 친한 친구

④ 나를 토론이나 실험에 끼워주려고 애쓰는 친구

⑤ 나에게 상관하지 않는 친구

⑥ (기타의견 :)

(2) 그 이유는 무엇입니까?

10. 이전에 소집단 활동을 할 때, 나는 주로 어떤 사람이었나요?

① 지식 내용을 제공하는 사람

② 토론을 활발히 도와주는 사람

③ 혼자 과제 수행하는 사람

④ 과제에 참여하지 않는 사람

⑤ 수업을 방해하는 사람

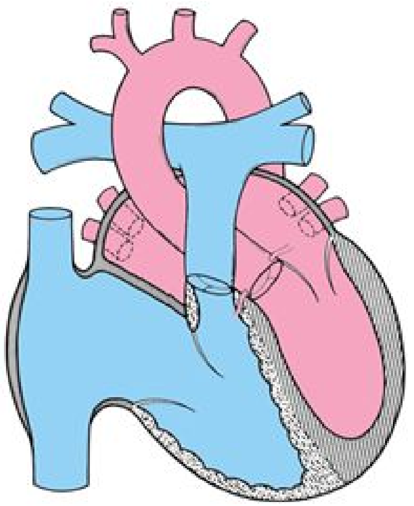
⑥ (기타 :)

생각해봅시다

※ 아래 그림은 심장의 내부구조를 간단히 나타낸 것입니다. 물음에 대해 생각해보고, 자신의 생각을 적어봅시다.

① 심장은 어떤 역할을 하나요?

② 심장 안에서 혈액은 어떤 방향으로 흐를지 아래 그림에 화살표로 나타내고, 왜 이러한 흐름이 생기는지 설명해보자.



Appendix 2-1. Students' worksheet (Lesson 1)

활동지 1	탐구주제 : 펌프와 심장박동	조
	2011년 월 일 2학년 반 번 이름 :	

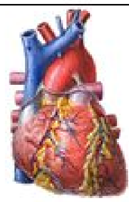
준비물

펌프 2개(석유나 물을 옮기는 펌프), 수조 2개, 활동지

활동하기

◉ 활동 1 : 펌프와 심장박동

관을 뺀 펌프를 물에 넣고 수축·이완시키면서 물의 흐름을 관찰하자.

펌프	심장
 	

1) 펌프를 심장에 비유할 때, 심장에서 펌프를 누르는 힘과 같은 역할을 하는 것은?

2) 심장은 1분 동안 70회 정도 위와 같은 운동을 한다. 심장이 펌프 역할을 잘 하려면, 어떤 구조를 가져야 할지 모둠원들과 이야기한 후 적어보자.

◉ 활동 2 : 펌프의 막과 심장 판막의 기능 (모둠 활동)

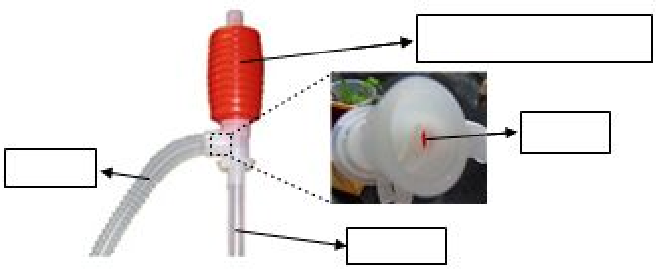
A, B 두 개의 펌프를 이용하여, 한 수조에서 다른 수조로 물을 옮기면서, 두 펌프에 차이가 있는지 알아보자.

1) 두 펌프의 물이 흐르는 방향을 화살표로 표시해보자. 두 펌프가 차이가 있다면 무엇 때문인지 펌프를 분해해서 내부 구조(막의 유무, 위치, 개수 등)를 관찰하고, 물이 흐르는 방향과 펌프의 구조를 연결 지어 생각해보자.

펌프의 종류	A	B
물이 흐르는 방향		
원인(펌프의 내부 구조와 연결 지어 생각해보기)		

2) A펌프를 수축·이완할 때 펌프 속의 2개의 막이 어떻게 움직이는지 관찰하고, 막 2개의 움직임이 어떻게 물을 한 방향으로만 흐르게 하는지 모둠원들과 의논하여 적어보자.

3) 아래 펌프의 각 구조를 심장에 비유했을 때, 심장의 어디에 해당할지 교과서 그림(163쪽)을 보고 적어보자.



Appendix 2-2. Students' worksheet (Lesson 2)

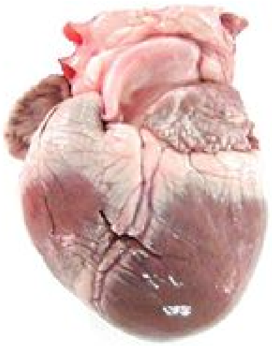
<table>
<tr><td rowspan="2">활동지 2</td><td colspan="7">탐구주제 : 심장을 관찰하자</td><td>조</td></tr>
<tr><td>2011년</td><td>월</td><td>일</td><td>2학년</td><td>반</td><td>번</td><td colspan="2">이름 :</td></tr>
</table>

준비물

돼지 심장, 해부용 칼(메스), 해부용 가위, 핀셋, 해부 접시, 의료용 장갑

관찰하기

1. 돼지 심장의 겉모습과 심장과 연결된 혈관을 관찰해 보자. (구멍이 많은 쪽이 뒤쪽)



1) 우심방, 우심실, 좌심방, 좌심실을 구분해본다.

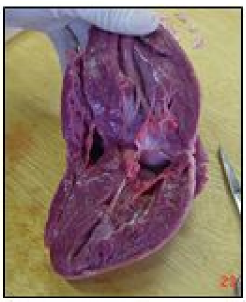
2) 혈관의 두께를 비교하여, 동맥과 정맥을 구분해보자.

3) 4개의 혈관에 두 개의 손가락을 넣어 손가락이 만나는 혈관과 만나지 않는 혈관은 무엇인가?

만나는 혈관	
만나지 않는 혈관	

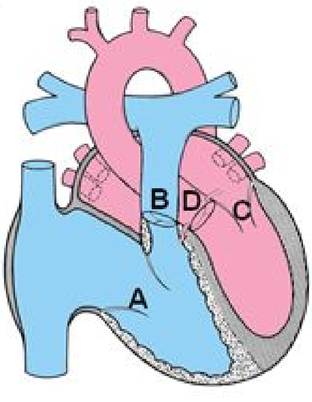
4) 3)번에서 손가락이 만나서 혈관이 연결되어 있다는 것은 무엇을 의미하는가? 손가락이 만나지 않아 혈관이 연결되어 있지 않다는 것은 무엇을 의미하는가?

2. 돼지 심장을 해부하자. 각 구조의 모습과 특징을 관찰하고 기능과 연결하여 생각해보자.



사진과 같이 심장을 횡단면으로 잘라 내부를 관찰한다.

※ 해부칼을 사용할 때 손을 다치지 않도록 주의한다!



1) 심장 내부의 두께를 관찰해 보자. 가장 두꺼운 곳은 어느 곳인가? 이유는 무엇일까?

2) 심방과 심실에 연결된 혈관에 손가락을 넣어 어느 곳에 연결되어 있는지 다시 확인해 보고, 대동맥, 대정맥, 폐동맥, 폐정맥을 구분해보자.

3) 돼지의 심장에는 사람과 같이 4개의 판막이 있다. 4개의 판막을 찾아보자.

4) 폐동맥 안의 판막을 자세히 관찰해보고, 판막이 무슨 역할을 할지 추론해보자.

5) 위 그림에서 판막이 없을 때 **우심실이 수축하면** 이곳의 혈액은 어디로 나갈 수 있는가? 판막이 있을 때는 우심실의 혈액이 어느 방향으로 이동할까?

	혈액의 흐름
판막이 없을 때	
판막이 있을 때	

3. 펌프 모형과 심장 구조를 생각하면서, 심장 내에서 혈액이 어떻게 이동하는지 모둠원과 의논하여 그림으로 그리고, 그림을 그렇게 그린 이유를 설명해보자.

Appendix 2-3. Students' worksheet (Lesson 3)

활동지3	탐구주제 : 혈액 순환	조
	2011년 월 일 2학년 반 번 이름 :	

준비물

4절지(A2) 종이, 싸인펜이나 색연필(빨간색, 파란색, 검은색), 연필, 지우개, 가위, 풀

활동하기

1. 4절지(A2) 종이 위에 사람의 외곽선을 그린다.
2. 뇌, 심장, 폐, 근육 그림을 오려서, 사람의 외곽선 위에 올려놓고, 기관의 명칭을 쓴다.
3. 심장의 각 부분의 명칭을 적는다.
4. 기관과 기관을 연결하는 동맥과 정맥을 선을 그려 표시하고 혈관의 이름을 쓴다.
5. 혈관 내에서 혈액의 흐름을 화살표를 이용하여 그려본다.
6. 산소가 많은 혈관에 빨간색의 색연필로 표시한다.
7. 산소가 적은 혈관에 파란색의 색연필로 표시한다.
8. 각 혈관에 흐르는 혈액에 대한 특징을 모둠별로 토의하고 혈관 옆에 쓴다.
   (산소, 이산화탄소, 영양분, 노폐물의 양)

평가하기

우리 모둠에서 그린 그림과 발표한 다른 모둠에서 그린 그림을 비교해보자.

▶ 다른 모둠의 발표를 듣고, 우리 모둠이 개선해야 할 점을 모둠원들과 의논하여 적어보자.

▶ 우리 모둠의 인체 내 혈액 흐름도를 개선해보자.

초 록

중학생의 혈액 순환에 대한 소집단 모델링 과정에서 나타난 인지적 협력 이해

이신영
서울대학교 대학원
과학교육과(생물전공)

과학자들은 자연 현상이나 체계에 대한 설명을 하기 위해 모델을 생성, 평가, 수정하는 모델링을 통해 다른 사람들과의 의사소통을 시도하려고 한다. 과학 교육에서도 모델링 실행은 학생들의 학습에서 중요한 역할을 한다. 학생들이 모델링 과정에 참여함으로써 자연세계에 대한 설명을 생성하고 평가하며 수정하는 인식론적인 경험을 하기 때문이다. 이에 본 연구는 학생들의 인지적 협력을 통한 모델링 학습을 장려하기 위해서 중학교 학생들을 대상으로 하는 혈액 순환이라는 주제로 소집단 모델 기반 탐구 수업을 설계하였다. 이를 토대로 학생들의 소집단 모델링 학습 과정에서 나타나는 인지적 협력을 통한 인식적 실행 과정을 이해하고자 하였다. 이를 위해 다음의 세가지 연구를 수행하였다.

'협력적 모델링에서 나타나는 소집단 모델 발달 유형과 추론 과정에 영향을 미치는 요인' (3장)에서는 심장 내 혈액의 한 방향 흐름에 대한 소집단 모델을 구성할 때 모델 발달 유형과 다양한 추론이 나타나는 원인을 연구하였다. 서울의 한 영재원에 소속되어 있는 14명의 중학교 2학년 학생들이 모델링 기반 수업에 참여하였다. 참여자들은 심장 내

의 혈액의 한 방향 흐름에 대한 소집단 모델을 구성하는 과정에 참여하였다. 연구 결과 소집단 모델 발달 유형은 정체형, 첨가형, 정교형이 나타났다. 소집단 모델 발달 유형은 학생들의 상호작용에 따라 결정되었으며, 많은 사례에서 정교형이 나타났다. 정교형 모델링이 나타나는 경우에 다양한 논변 요소가 나타나는 높은 수준의 추론과정이 일어났다. 비유 모형 활동과 내부 갈등은 수준 높은 추론 과정이 일어나도록 하여 초기 모델을 정당화하고 소집단 모델이 목표 모델에 도달할 수 있도록 하였다.

수준 높은 소집단 모델 발달 과정이 나타나기 위해서 모델 평가가 중요한 역할을 한다는 3장의 결과를 바탕으로, '모델 평가 수준에 따른 인식론적 특징과 모델의 질'(4장)에서는 학생들이 모델을 평가하는 수행 수준에 따라 나타나는 인식론적인 특징들을 탐색하였다. 또한 높은 수준의 모델 평가가 나타나는 맥락을 이해하기 위해 인식론적인 특징을 인지적 추론 과정을 통해 알아보았다. 인천의 K 여자 중학교 2학년에 재학중인 34명의 학생들이 3차시로 이루어진 모델링 기반 수업에 참여하였다. 학생들의 인식론적 특징과 모델의 질을 분석하기 위해, 혈액순환도를 그리는 3차시 수업에서의 모델링 과정과 소집단 모델을 분석하였다. 평가 수준은 모델의 변화가능성에 대한 인식과 현상을 설명하는 모델의 설명력을 평가하는 기준에 의해 4단계로 나누어졌다. 4수준의 모델 평가에서 학생들은 소집단 모델이 평가되어야 한다는 지식에 대한 인식론적인 신념을 바탕으로, 모델이 현상의 과정이나 메커니즘을 잘 설명하고 있는지에 대해 검증하였다. 이 과정에서 현상에 대한 모델의 설명력을 심층적 기준(more comprehensive criterion)을 이용하는 추론 과정에 의한 정당화 과정이 나타나면서 모델이 정교화되어 세련된 모델이 생성되었다.

4장에서 높은 수준의 모델 평가에서 학생들은 자신의 또는 타인

의 이해를 점검하는 발화에 의해서 인지적 협력을 통한 추론 과정이 정교하게 나타났다. 이에 ‘심층적 접근방식의 출현과 소집단 모델링에서의 인지적 협력’(5장)에서는 모델링 활동 특성에 따라 나타나는 심층적 접근방식의 발화를 알아보고, 소집단 모델링에서의 인지적 협력을 심층적 접근방식의 발화에 초점을 맞추어 살펴보았다. 소집단 모델링 과정에서 나타나는 학생들 개인의 학습접근방식의 시너지 효과를 깊이 있게 이해하고자 하였다. 4장 연구참여자들 중 한 조를 선발하여 4명의 학생들에 대한 사례연구를 실시하였다. 학생들이 참여한 3차시로 구성된 혈액 순환에 대한 모델링 수업에서 드러난 학생들의 인지적 참여 과정을 분석하였다. 연구 결과 각 수업의 모델링 관련 특성에 따라 추론 과정이 다르게 나타남으로써 각 수업에서 두드러지는 심층적 발화의 하위 범주가 다르게 나타났다. 또한 심층적 발화는 논변적 담화 실행의 목적을 가지고 있었으며, 개인의 심층적 발화는 소집단 모델링 과정에서 인지적 스캐폴딩과 비판적 모니터링과 같은 인지적 협력과 모델 발달 과정에 영향을 미쳤다.

이와 같은 연구 결과를 통해 중학교 학생들이 소집단 모델링 과정에서 상호작용을 통한 인지적 협력 과정을 이해할 수 있다. 이러한 이해를 바탕으로 과학 수업에서 학생들이 과학의 인식적 실행을 경험할 수 있는 진정한 소집단 모델링 수업을 할 수 있도록 지원해주어야 한다.

주요어 : 인지적 협력, 소집단 모델링, 혈액 순환, 모델 평가, 실행적 인식론, 심층적 학습접근방식

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