Exploring the Argumentation Pattern in Modeling-based Learning about Apparent Motion of Mars

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This study proposed an analytic framework for coding students' dialogic argumentation and investigated the characteristics of the small-group argumentation pattern observed in modeling-based learning. The participants were 122 second grade high school students in South Korea divided into an experimental and a comparison group. Modeling-based learning was applied to the experimental group in a topic of apparent motion of Mars on the other hand, explanation-based classes led by a teacher were provided to the comparison group with the same topic. Students created a paper model of Mars retrograde motion and learned through small-group discussion about the astronomical phenomena which is represented by the created model and the reason that caused these phenomena. The analytic framework for coding students' argumentation in the modeling-based learning was composed into eight components and three categories including model-related statement, claim and reasoning. The results showed that a variety of model exploration is essential for useful argumentation which includes the reasoning added with the claims. By investigating the time sequential pattern of the argumentation, a process of argumentation frequently cross all three categories was revealed as an effective pattern in modeling-based learning. Additionally, the results of comparing the concepts of apparent motion of Mars in the experimental group and comparison group, the ratio of students with correct concepts of the experimental group was higher than those of the comparison group. The implication of these finding for modeling-based learning environment, productive modeling discourse are discussed.

Keywords: argumentation, modeling-based learning, apparent motion of Mars, analytic framework

INTRODUCTION

Modeling-based learning is the approach of using modeling during learning in science, which can provide the context in which the construction and refinement of models can achieve better conceptual and operational understanding of the nature of science (Bell, 1995; Grosslight, Unger, Jay, & Smith, 1991; Harrison & Treagust, 2000;

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Schwarz, 2009; Sins, Savelsbergh, van Joolingen, & van Hout-Wolters, 2009; Windschitl, Thompson, & Braaten, 2008). Modeling can provide students opportunities to think and talk scientifically about physical phenomena (Penner, 2001; Schwarz et al., 2009), to share, discuss, and criticize their ideas (Devi, Tiberghien, Baker, & Brna, 1996) and to reflect upon their own understanding (Gilbert, Boulter, & Rutherford, 1998; Gilbert, Boulter, & Elmer, 2000; Jonassen, Strobel, & Gottdenker, 2005).

Scientific argumentation requires individuals to gather and make sense of data, generate and articulate explanations for natural phenomena, justify explanations with appropriate evidence and reasoning, and critique the validity and legitimacy of one or more viewpoints. Current research indicates that when students engage in these types of activities on a regular basis they can learn science content (BellForman & Linn, 2000; Zohar & Nemet, 2002), develop complex reasoning and critical thinking skills (Lawson, 2003; Sadler, 2004; Siegel, 1995), understand how knowledge is generated and validated in science (Driver, Newton & Osborne, 2000; Osborne, Erduran & Simon, 2004), and improve their communication skills (Kuhn & Udell, 2003). Moreover, the latest studies investigate the influence of group dynamics in online environment (Ryu & Sandoval, 2015) and pre-service science teachers' argumentation in online discussion (Isbilir, Cakiroglu & Ertepinar, 2014). Although the theoretical support for the use of argumentation in science classrooms is present, we have limited knowledge of best practices that can improve students' scientific model building through argumentation. If we want argumentation-based pedagogy to prevail in science classrooms, we need to research and identify effective instructional strategies to graft argumentation onto the learning models. We designed this study to make contributions to these efforts. More specifically, we designed this study to explore the impact on argumentation, coupled with modeling-based learning experience about the apparent motion of Mars.

State of the literature

- Modeling-based learning have been recognized as a valuable teaching tool that changes alternative conceptions into scientific conceptions.
- Toulmin's argument pattern has been applied as a methodological tool for the analysis of students' reasons and justifications in the context of science lessons.
- Although a wide range of research on modeling has been provided, there is limited knowledge of characteristics of students' dialogic scientific argumentation that are observed in modeling-based learning.

Contribution of this paper to the literature

- The analytic framework proposed by this study provides a useful codes for analyzing the small-group argumentation, to identify how learners interact with each other for modeling-based learning.
- This study empirically examines that a time sequential pattern of argumentation frequently cross all three categories including model exploration, claim and reasoning, is a useful pattern in modeling -based learning.
- The results of the study is encouraging in that teachers should involve dialogic argumentation when students have difficulties in connecting the results of observing and related scientific concepts.

Modeling-Based Learning in Science

Models and modeling can help learners build subject matter expertise, epistemological understanding, and practices and skills such as systems thinking (Lehrer & Schauble, 2006; Lesh & Doerr, 2003; Schwarz & White, 2005). Furthermore, engaging learners in modeling-based learning can help them develop their scientific literacy—deepening their scientific knowledge through generating, evaluating, and revising their thinking in a community of practice so that they can make more informed personal and more effectively participate in the world.

Models of physical phenomena are epistemological constructs of the physical sciences and provide operational descriptions of physical systems (Driver & Oldham, 1986; Hestenes, 1997; Prins, Bulte, & Pilot, 2011; Sensevy, Tiberghien, Santini, Laube, & Griggs, 2008; Park, 2013). These models seek to acquire permanent status, until new evidence indicates a mismatch between the model and the physical situation, in which case a revision of the model becomes necessary to account for the new evidence (Duschl, 1990). In this sense, science is viewed as a complex and dynamic network of models, which are the core components of scientific theories and they take a central role in the formation and the justification of scientific knowledge (Koponen, 2007; Pluta, Chinn, & Duncan, 2011; Schwarz et al., 2009). Models are constructed through modeling (Fretz et al., 2002), a process of developing representations of the concepts and mechanism(s) that are involved in a physical phenomenon (Windschitl, Thompson, & Braaten, 2008). In scientific research, models are used for formulating hypotheses to be tested and to describe scientific phenomena (Gilbert, 1995; Pluta, Chinn, & Duncan, 2011), and therefore, modeling plays a central role in the justification and formation of knowledge (Koponen, 2007). Hence, models and the process of modeling have been indicated as core components of scientific endeavors (Gilbert, 1991; Linn, 2003).

Fretz et al. (2002) describe a distinction between two different modeling-based learning approaches. In the first approach, namely, relation-based thinking in science, students decompose the physical system under study into smaller easily identifiable parts and explore how the system's parts are causally related with each other. This leads to a network of interconnected observable features of the system with the explicit description of their relationship(s) but without any representation of the system parts' underlying causes. In other words, in relation-based thinking students identify the physical objects involved in the phenomenon to be modeled, and possibly their physical behavior(s). Alternatively, in the second approach, namely model-based thinking in science , students develop a representation of the mechanisms that cause the behavior of the physical system by identifying key players in those parts (physical objects), their characteristics (physical entities), and their behaviors (physical processes). This can lead to the development of various relationships between objects and variables which can represent the physical system under study and recreate its behavior. This approach assumes that the behavior of a phenomenon arises from its objects and thus, it engages students in the process of building and testing models of physical systems based on the representation of the underlying causality of physical systems.

Each of Fretz et al.'s (2002) approaches engages learners in different ways of thinking and possibly in diverse types of activities, and promotes the construction of different kinds of models. This distinction raises an important issue related to the type(s) of student modeling discourse that is productive for modeling-based learning. To offer a working definition, we take productive modeling discourse to include student modeling conversations that lead to the construction of causal models of physical phenomena. By causal models (Louca, Zacharia, Michael, & Constantinou, 2011), they refer to models that include representation(s) of the underlying mechanism that causes behavior of the physical phenomenon (Lesh & Doerr, 2003), which includes entities that cause change in the physical processes involved. To achieve this, causal models include representation(s) of the physical objects involved, the physical entities, the physical processes and interactions between physical objects, entities, and processes (Constantinou, 1999; Gilbert, 1995; Glynn & Duit, 1995; Hestenes, 1992).

A modeling centered inquiry approach also includes a focus on helping learners understand that modeling-centered inquiry is a dynamic process that involves iteratively revising models to be consistent with theory and evidence and that models can be used to predict and explain multiple phenomena in the natural world (Schwarz & White, 2005; Schwarz et al., 2009). Modeling-based learning achieved by the reasoning on the experimental results, however different modeling is required for the planets' apparent motion as direct experimental study is difficult for this. Thus, in this study modeling-based learning was attempted to promote or support students create their paper model, compare the created model with the natural objects through argumentation, and construct their own mental models.

Theoretical Perspective on Argumentation

Argumentation is a fundamental discourse of science, a part of the practice of science for developing, evaluating, and refining scientific theories about the natural world (Duschl & Grandy, 2007; Duschl & Osborne, 2002; Osborne, Erduran & Simon, 2004; Simon, Osborne & Erduran, 2003; Erduran & Osborne, 2005). Scientists argue over the questions they pose, the methods of investigations they use, the nature and source of evidence they use, and the conclusions they arrive at (Kuhn, 1992; Latour & Woolgar, 1986). Students are challenged and helped to construct knowledge by engaging in such activities as sharing of information, responding to the questions posed by members of the community and challenging the validity of responses to those questions collectively, and backing claims to knowledge with evidence (Bricker & Bell, 2008; Kuhn, 1993). In spite of its centrality to the process of science, argumentation is rarely used in the teaching and learning of science (Driver, Newton & Osborne, 2000; Erduran & Jimenez-Aleixandre, 2008; Erduran, Ardac & Yakmaci-Guzel, 2006; Kuhn, 2010).

Whereas there is a substantial amount of research regarding the positive effects of argumentation on science knowledge development, research exploring the relationship between knowledge and argumentation is not prolific. Therefore, there is a need for studies tracing the relationship between students' involvement with argumentation and their scientific knowledge during the argumentation process.

Through his well-known book titled The Uses of Argument, Stephen Toulmin has made a significant impact on how science educators have defined and used argument. Toulmin's definition of argument (Figure 1) has been applied as a methodological tool for the analysis of a wide range of school subjects including science (e.g., Jimenez-Aleixandre, Rodrıguez, & Duschl, 2000; Zohar & Nemet, 2002), history (Pontecorvo & Girardet, 1993), and English (Mitchell, 1996).

In the context of science lessons, the use of Toulmin's Argument Pattern (TAP) has mainly concentrated on the description of small-group discussions among students. For instance, Jimenez-Aleixandre, Rodrıguez, and Duschl (2000) have used TAP to examine students' reasons and justifications in the context of high school genetics lessons. TAP illustrates the structure of an argument in terms of an interconnected set of a claim; data that support that claim; warrants that provide a link between the data and the claim; backings that strengthen the warrants; and finally, rebuttals which point to the circumstances under which the claim would not hold true. More specifically, in Toulmin's definition, a claim is an assertion put forward publicly for general acceptance. Grounds are the specific facts relied on to support a given claim. Backings are generalizations making explicit the body of experience relied on to establish the trustworthiness of the ways of arguing applied

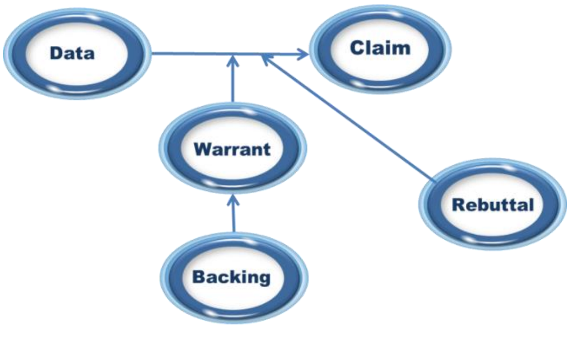

Figure 1. Toulmin's argument pattern (Toulmin, 1958).

in any particular case. Rebuttals are the extraordinary or exceptional circumstances that might undermine the force of the supporting arguments. In practice, a strict application of Toulmin's argument pattern is difficult (Erduran, 2008; Erduran et al., 2004), but it remains a popular approach to characterizing argument structure. Some have argued (Duschl, 2008) that the application of Toulmin's pattern in science education has ignored Toulmin's own point that the quality of particular arguments is what he called "field-dependent." That is, the structure of an argument alone does not capture the extent to which warrants are appropriate justifications or proper rebuttals that make sense. Such judgments can only be made within fields (or disciplines) and rest of analyses of the substantive content of arguments.

Given this theoretical perspective, we have conceptualized dialogic argumentation as a process of proposing, supporting, evaluating, and refining ideas in an effort to create a mental model. Our efforts to support and promote argumentation in science class have therefore focused on the development of a model-based learning environment that enables students to generate competing explanations for a given phenomenon, and then provides them with an opportunity to examine, discuss, and evaluate these explanations. In our approach, we have adopted TAP to investigate argumentation in small-group discussions among students. Our work extends the use of TAP in argument analysis by generating and applying TAP as a quantitative as well as a qualitative indicator of the teaching and learning occurring in classrooms.

Purpose of the Study and Research Questions

Since there has been an insufficient amount of studies dealing with the concept of retrograde motion of Mars, it is currently needed to proceed a research investigating the learning process in the use of apparent motion model of Mars. It is anticipated to identify detailed modeling learning process by analyzing how small-group argumentation is conducted in the modeling process in apparent motion of Mars.

Therefore, the primary objective of this study is to investigate the characteristics of the small-group argumentation patterns are observed in the modeling-based learning about apparent motion of Mars, and to ascertain when it becomes productive. Under the purposes of this research, the following questions were addressed:

- How can we identify and characterize the nature of students’ argumentation in modeling-based learning?
- What are the characteristics of the small-group argumentation frequency pattern in modeling-based learning about the apparent motion of Mars?
- What are the characteristics of the small-group argumentation time sequential pattern in modeling-based learning about the apparent motion of Mars?
- How different are the concepts of apparent motion of Mars in the experimental group who conducted modeling-based learning from those of the comparison group?

METHODOLOGY

Participants

A total of 122 second graders from a boy high school in South Korea participated in this study as subjects. Among them, 62 students from two classes were in the experimental group, and 60 students from another two classes were in the comparison group.

The education system in South Korea is divided into 6 years of elementary school, 3 years of middle school and 3 years of high school, and the target schools, which the participants attended, was located in one of the largest cities in Korea. Classes with students participating in this study belonged to the track of natural sciences that aimed to advance to science and engineering college. According to the result of achievement test conducted prior to this study on the experimental group and comparison group, there was no statistically significant difference between the groups. Modeling-based learning was applied to the experimental group in a topic of apparent motion of Mars. Among students in the experimental group, activities by two teams were video recorded and used as data for the study. Explanation-based classes led by a teacher were provided to the comparison group with the same topic.

Procedures

Experimental group was organized by five students with a different level of academic performance as a small-group for modeling learning. A three-dimensional drawing sheet that represented the apparent motion of Mars was developed and provided to students. Students created a model and learned through small group discussion about the astronomical phenomena and causes of them. As for materials, six pieces of strawboard, scissors, tape, a thin stick with stubby edges, ink, and pens (black and red) were used. As shown in Figure. 2, revolutionary orbit of earth and Mars drawn by two strips was sketched on the strawboard. However, when creating the revolutionary orbit of Mars, the dent mark 4 shall be higher than the other adjacent two marks by 0.6cm followed by slowly being lowered.

After cutting two strips by using scissors and knives, fold the slashed areas into circular shape by using glue. Draw a straight line on the floor strawboard that passes through the center and indicate the location of the sun in the center of a straight line. Fix the orbit of two planets so that the sun is located inside of the orbit of the planet on the floor strawboard. Draw a circular arc relevant to the celestial sphere on the floor strawboard and use another strawboard to make it vertical in a circular shape. Teacher need to inform students that the real celestial sphere is an infinite distance away, but a certain artificial distance is kept in the experiment. Students are led to create a model by experiencing trials and errors. In case that they experience difficulty, teacher shall help them. The location of apparent motion of Mars and also a created model is shown in Figure 3.

In order to dot the positions of apparent motion of Mars, put the black ink at tip of a stick and place it on the dent mark 1 in the earth and Mars. Place a dot on the position where meets the strawboard of the celestial sphere and label the number. Repeat the same procedure until the dent mark 7 and connect dots on the celestial sphere with black pen in order. Vertically set another celestial sphere on the opposite side, place a dot on the position above the sun and the dent mark 1 of the earth with the stick, and label the number. Repeat the same procedures until the dent mark 7 and connect dots on the celestial sphere with red pen in order. Aforementioned procedures of manufacturing three-dimensional model were performed in the first 90 minutes in the class. After discussing for 90 minutes a day after by each team, students prepared for the work sheet and was presented by each group. Topics covered in the discussion by each team are as follows.

Topic 1. What is the reason that the Mars strip was made to be bulged out a little bit on the model?

Topic 2. What are characteristics of movement direction of the sun and Mars shown in the model?

Topic 3. How is the positon of Mars related to the earth when Mars seems to move in an opposite direction of the sun? At this time, how is the right ascension of Mars changed?

Topic 4. Why is the distance between dent marks on the earth and Mars different? How will the apparent motion of the Mars if the distance of dent marks is kept the same?

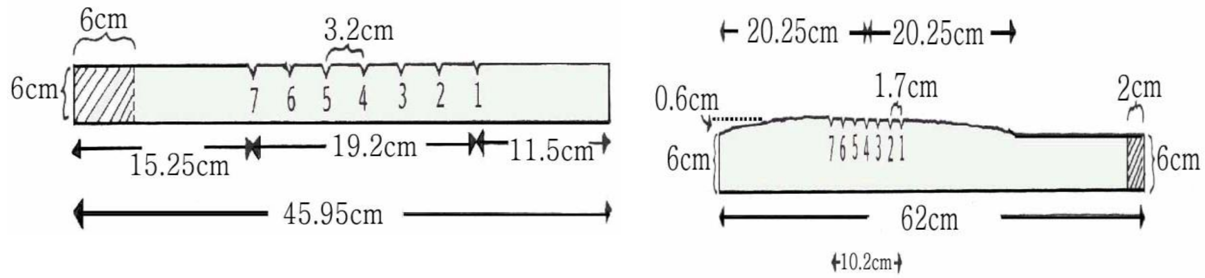

Figure 2. Drawing sheet of Earth and Mars strips for creating the model

Figure 3. A model created by students and dotting the positions of Mars

On the other hand, two sessions of 60-minutes long lectures were provided by the same teacher to the comparison group. Students wrote major content on the study materials after listening to the teacher's explanation. The teacher utilized visual and auditory materials including video clips of apparent motion of Mars as a Power-Point presentation. The concept survey of the apparent motion of Mars was provided to the experimental group and comparison group two days after the class. Questions regarding the concept of apparent motion of Mars were created and used in person. Concept survey was comprised of four questions asking students to describe the apparent motion of Mars and one question for drawing it like that, which were developed by researchers after discussing it with each other. Afterwards, the validity was approved by two earth science teachers. The survey was administered by the teacher, and students were given 20 minutes to complete the survey. To ensure the uniformity of administration of the survey in all classrooms, the teacher was instructed not to provide students with any clarification or additional information beyond what was written in the survey. The instrument presented in this article was translated from English to Korean and reviewed by a researcher fluent in English. The entire modeling-based learning processes conducted two teams; one team from each one of two classes, were video-taped. Analytical tools were developed for the argumentative dialogue. Based on them, the argumentative dialogue on four topics was analyzed. As for the source of data for this study, video-taped transcripts provided to two teams in the experimental group and the results of concepts survey performed on the experimental group and comparison group were used.

Data Sources and Coding

Since Toulmin's argument pattern (TAP) is useful for argumentation analysis of individuals as an analytical tool, research dealing with individual discussion have been performed (Sampson & Clark, 2008). Analysis of the communication by TAP focuses on whether to have major discussion elements or the frequency of them. Therefore, the quality of the discussion is not well evaluated (Clark et al., 2007; Yore & Treagust, 2006). Furthermore, since it is difficult to identify the interactive characteristics of the results of analysis shown in terms of whether to have discussion components the frequency of them, they are not helpful in properly instructing the argumentation (Hogan & Maglenti, 2001; Zohar & Nemet, 2002). Analytical tools that supplemented the TAP for the analysis of argumentation process were suggested by

Erduran et al. (2004). They have suggested five-step argumentation level in the perspective of justification and also whether to have rebuttal in order to distinguish the qualitative argumentation processes of team members that were shown in conversational discussion. Similarly, Clark & Sampson (2008) have suggested six-stage level by regarding the rebuttal on other grounds (data, guarantee, and supplementation) instead of the rebuttal of claim by segmenting it in more details. These two studies were of a trial for the conversation-based argumentation process analysis and also made it feasible to proceed discussion on the quality aspects. However, such an analysis focused on whether to have rebuttal or justification. Therefore, it entails an issue of not considering detailed frequency of each of the discussion components. This study aims to find argumentation process components occurring in modeling-based learning and investigate the time sequential pattern of the argumentation as well as frequency of argumentation components. Hereupon, it will be feasible to identify how learners interact with each other for modeling learning and which argumentation patterns are more useful in constructing scientific concepts.

Argumentation analytical framework in the previous research (Toulmin, 1958) was referred to in this study that we developed the argumentation analytical framework by primarily analyzing the full transcripts of modeling-based learning of two teams. All of the codes presented here were developed, refined, and applied by the author and two other researchers including who the teacher taught earth science for this study. The Microsoft excel program format was created using function in order to deal with transcribed data. We analyzed the full transcript of students based on pre-determined analytical components. In this process, we have re-discussed the discourse with a lower level of consistency between coders and finally determined them. The eight coding components in the three categories were confirmed as shown in the Table 1. In the model-related statement category of coding components, question about the model (QM), observation on the model (ObM), and inquiry method (InqM) were included. In the claim category, claim based on observation (ClaO) and claim based on knowledge (ClaK) were included. In the reasoning category, rebuttal (Reb), warrant (Wa), and backing (Bac) components were included for supporting and justifying the claim.

Three coders independently coded a random selection of 30% of the transcripts. Reliability was calculated with Cohen's Kappa. Kappa was .70, which is acceptable. The examples of analysis on the students' argumentation based on the coding components are as follows in Appendix 1.

Table 1. Coding components of analytical framework for the students' argumentation in the modeling-based learning

Categories	Components	Definition
Model-related statement	Question about the model(QM)	Questions about the created model
	Observation on the model(ObM)	Results of observing the created model
	Inquiry method(InqM)	Creating the model and suggesting the inquiry methods
Claim	Claim based on observation(ClaO)	Explanation of causes based on observation
	Claim based on prior knowledge(ClaK)	Explanation of causes based on prior knowledge
Reasoning	Rebuttal(Reb)	Statement against the claim
	Warrant(Wa)	Statement supporting the claim
	Backing(Bac)	Reinforce the warrant

FINDINGS

Results of Analysis in Frequency of Argumentation Components

Topic 1 is an inquiry of the reason that the Mars strip was made to be bulged out a little bit. The results of frequency analysis in the argumentation components of two teams are as shown in Figure 4.

According to Figure 4 on the result of comparing the frequency in model-related statement category of two teams, the frequency of question about the model (QM) was same in both teams, while the frequency of observation on the model (ObM) of team B was low compared to team A. In addition, suggestion about the inquiry method (InqM) was provided only once in team B. Frequency of claim based on prior knowledge (ClaK) was higher than claim based on observation (ClaO) in team A. Team A had difficulty in distinguishing between the revolutionary orbit and the apparent motion path of Mars in the model, hence repetitively stated simple prior knowledge.

On the other hand, team B had more claims based on observation (ClaO) of the revolutionary orbit and the apparent path of Mars with relatively less claims based on prior knowledge (ClaK). In the reasoning category, team A could not support or rebut while team B made the statement of rebuttal, warrant, and backing. Team A represented a simple pattern of model-related statements and claim, while team B showed the characteristics of model exploration and claim process added with reasoning. Therefore, team B showed a higher level of modeling-based learning than team A.

According to Figure 5 on the result of comparing the model-related statement category, team B had higher frequency on observation on the model than team A. The question about the model was shown in team B but not in team A. In the claim category, team A had claim based on prior knowledge but not claim based on observation. On the other hand, unlike team A, team B had claim based on observation. The frequency of claim based on prior knowledge was turned out to be similar. In the reasoning category, team A had only warrant, while team B had both rebuttal and warrant. However, backing was not shown in both teams. Team A observed model but was only able to explain it not based on observation but on prior

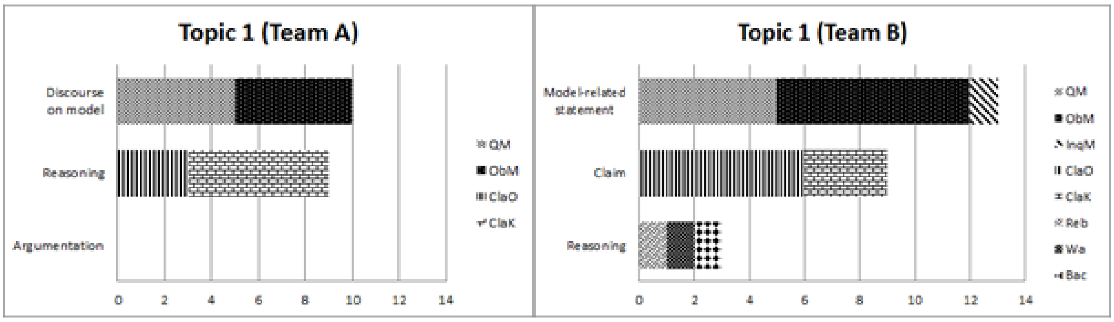

Figure 4. Two teams' frequency of each components in argumentation about topic 1

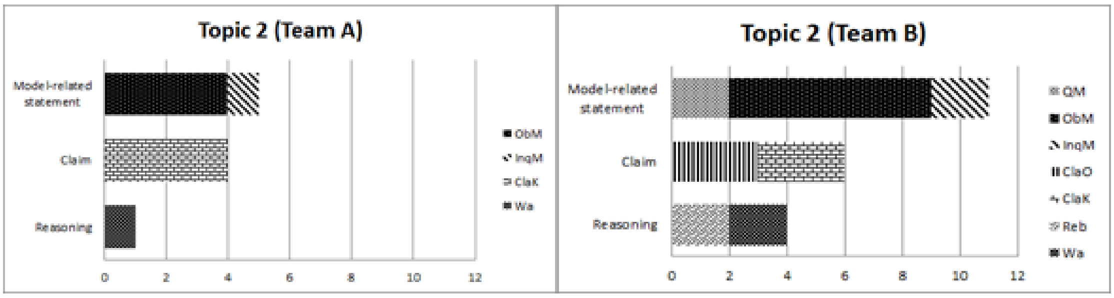

Figure 5. Two teams' frequency of each components in argumentation about topic 2

knowledge regarding motions of the sun and Mars. On the other hand, team B made an attempt to explain the movement direction of the sun and Mars based on the result of observation and mentally modeled them.

Topic 3 is about the explanation of sub-topic of how the position of Mars is related to the earth when Mars seems to move in an opposite direction with the sun, and how the right ascension is changed at this time. The results of analyzing frequency in argumentation components of two teams are as shown in Figure 6.

As seen in Figure 6, topic 3 has been the most actively discussed in a course of reasoning the relationship between the period of retrograde motions and the position of Mars and changes in the right ascension. According to the result of comparing the frequency of model-related statement, the frequency of suggesting the model observation and inquiry method was turned out to be similar. Questions about the model were shown more in the team B than team A. In the claim category, the claim based on knowledge was shown more in team A, while the frequency of claim based on observation was low. However, team B had higher frequency of claim based on observation than team A. Therefore, it represents that team B had a high level of discussion. In the reasoning category, both teams had a similar frequency of warrant, rebuttal, and backing. The number of them was shown a bit higher in team B. Team B observed the model and explained how Mars was located the nearest to the earth at the time of retrograde motions. However, team A stated prior knowledge instead of observation that retrograde motions of Mars was shown in opposition. In topic 3, the claim based on prior knowledge was shown more than the claim based on observation both in team A and B. Especially, both teams had a difficulty in observing and applying the model in the measurement direction of right ascension and position of vernal equinox. This was why it was difficult to observe movement direction of planets and the reference point of coordinates in the celestial sphere. Therefore, they represented a tendency of relying on prior knowledge that the right ascension was decreased at the moment of retrograde motions. We may argue that teachers need to explain it in

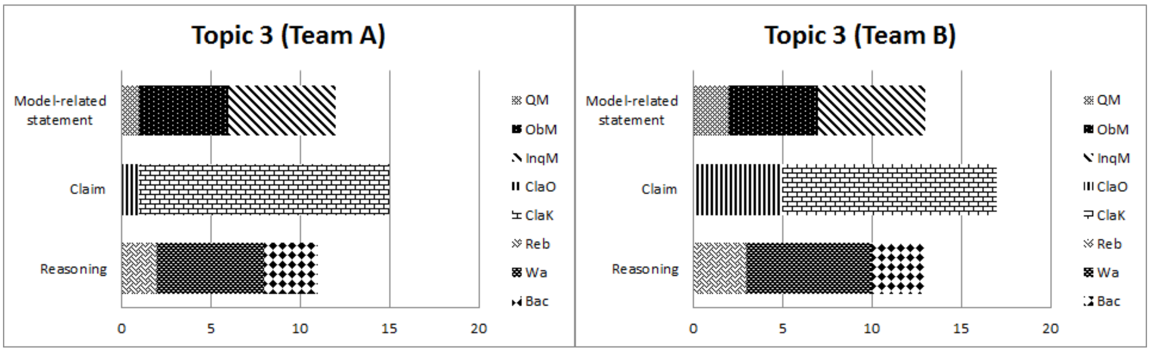

Figure 6. Two teams' frequency of each components in argumentation about topic 3.

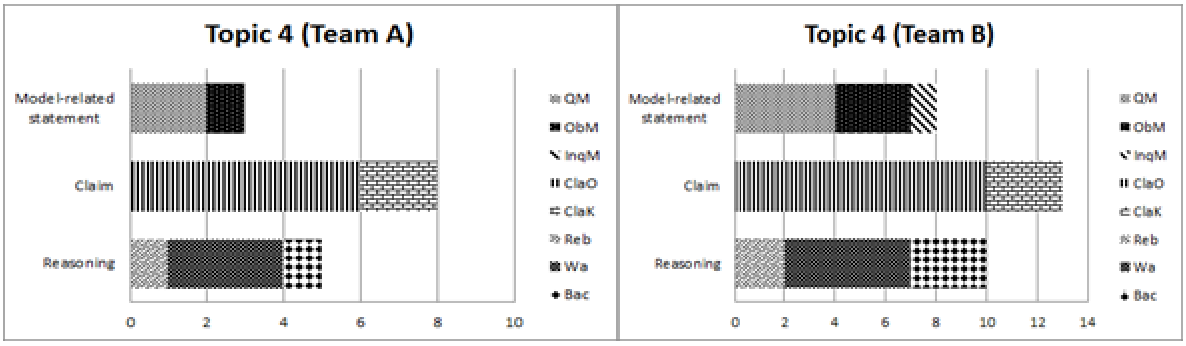

Figure 7. Two teams' frequency of each components in argumentation about topic 4.

relation to coordinate system and the model at this moment to help students extend their perspectives.

Topic 4 is to explain the reason why the dent marks on the orbit strip of the earth and Mars is different and also how apparent motion of Mars will turn out if maintaining the distance of dent marks is kept the same. The results of frequency analysis on argumentation components of two teams are as shown in Figure 7.

As seen in Figure 7, team B had a higher frequency than team A according to the model-related statement category. In the claim category, both teams had more claims based on observation than the ones based on prior knowledge. Especially, team B had more active claims based on observation for the model that represented a higher level of discussion than team A.

In the reasoning category, both team had warrant, rebuttal, and backing. However, the frequency was higher in team B. After deducing the reason why an angle between interval of dent marks on the revolutionary orbit and the center of the sun was different, a conclusion was made that the revolution speed of the earth was higher. This is a process of understanding the causes of retrograde motions of the Mars after exploring the model, explaining the causes, and disputing them. It is a case of successful modeling learning that inference was properly made in an attempt to explain the causes of model exploration.

Results of Time Sequential Analysis of Argumentation Components

The results of time sequential analysis of the entire modeling courses other than the frequency investigation of each of the argumentation components are as follows. The time sequential argumentation pattern of two teams about topic 1 is as shown in Figure 8.

According to Figure 8, team A had the pattern of model exploration and observation two times in a repetitive manner. Team A attempted to observe the model one more time since there was not rebuttal or warrant on the claim. Team B had relatively more frequent transitions between the model exploration and claim category compared to team A. In addition, team A had no warrant or rebuttal on the

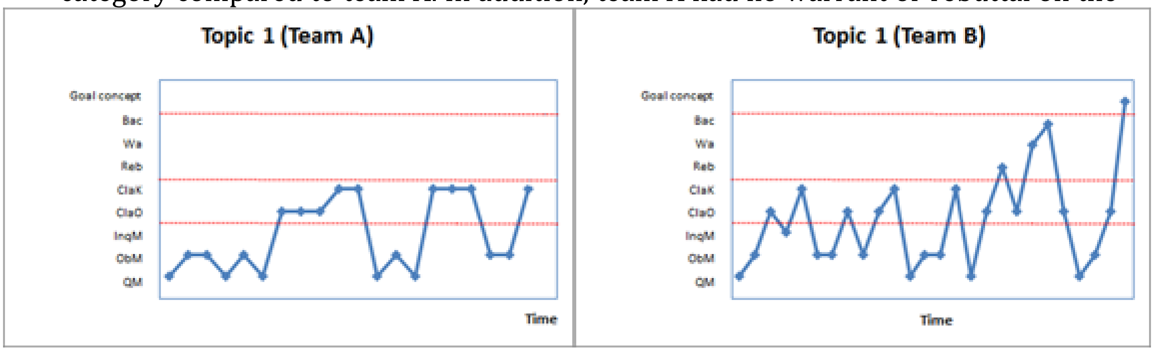

Figure 8. Two teams' time sequential distribution of argumentation about topic 1

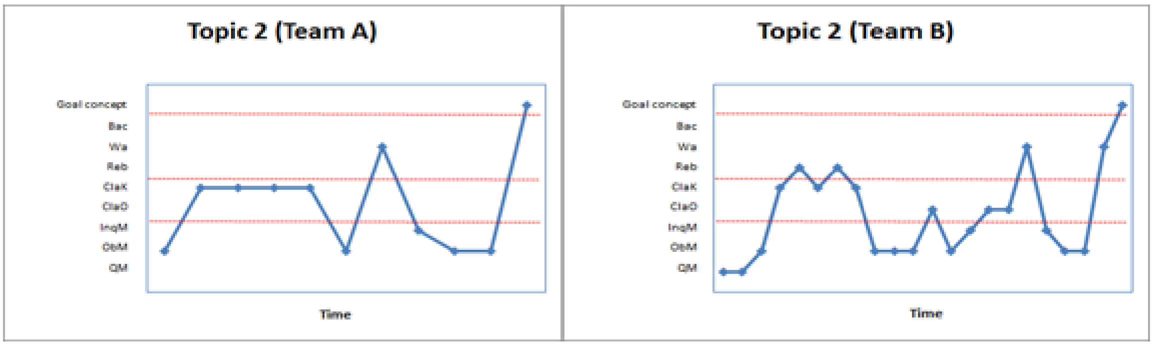

Figure 9. Two teams' time sequential distribution of argumentation about topic 2.

claim, while team B had rebuttal and warrant. Team A represented a pattern of the simplest pattern of model exploration and claim shown in the modeling learning but failed to reach the goal concept without reasoning process. On the other hand, team B made claim based on the observation of model and reached to the concept of goal after rebuttal in opposing the claim, warrant for justifying the claim, and backing for suggesting detailed cases for reinforcing the warrant. In other words, team B reached to the fact that the Mars strip was made to be a bit bulged out due to the difference of revolutionary orbit of the earth and Mars.

Time sequential argumentation pattern of two teams on the topic 2 is as shown in Figure 9. As seen in Figure 9, team A observed the model however attempted to provide claim based on prior knowledge multiple times and re-observed the model. They made an attempt to observe the model again but were unable to present claim based on them. There was claim based on prior knowledge, and the concept of goal was reached after providing warrant statement and observing the model. On the other hand, team B had question about the model and model observation in the beginning but was unable to connect them with claim based on observation. They only made claim based on prior knowledge. After repeating the rebuttal of such a claim and presenting another claim, an attempt was made to observe the model. An attempt was made again on claim based on observation of the model, and there has been discussion about inquiry methods. Afterwards, the claim based on observation was provided followed by warrant for supplementing such claim. On the last stage, there was suggestion again about the observation and exploration methods reaching the goal concept after the argumentative reasoning. We may argue that such time sequential argumentation pattern of team B is a case of successful modeling learning.

Topic 3 was to find answers of two sub-topics. First sub-topic was to derive the relationship with the position of the earth at the time of retrograde motions of Mars. As seen in Figure 10 both groups acquired the goal concept by utilizing prior knowledge for how it was in retrograde motions in the beginning stage. Team A represented that identical argumentation components were repeated, while team B showed various argumentation components in turn.

There was a tendency that team A was in the same category, while team B crossed frequently between claim and argumentation categories. Team A repetitively provided the same opinion with other students, while team B actively interacted with other students by exchanging opinion with one another. The second sub-topic was about changes in the right ascension of Mars at the time of retrograde motions. Team A observed the model but did not provide any claim on it. They only repeated claim based on prior knowledge and were not able to reach the goal concept. On the other hand, team B asked about the model and suggested inquiry methods and observed the model again. Afterwards, when providing claim based on them, they responded with rebuttal or warrant and finally reached the ultimate conclusion. After going through asking the model-suggesting the inquiry method-model observation-claiming based on the observation-reasoning reached the ultimate goal concepts. Therefore, a process of argumentation frequently cross all three categories of team B is regarded as a productive pattern of modeling learning.

The first sub-topic was to find the reason why the distance between dent marks on the orbit of the earth and Mars was different. According to Figure11, they acquired the goal concept grounded the claim based on observation and prior knowledge. The goal concept is that a distance of dent marks on the model caused the difference of the revolutionary speed of two planets. It is a case of successful modeling learning that inference was properly made in an attempt to explain the causes of model exploration. In the second sub-topic, team A had less frequency of argumentation and were not able to reach the goal concept.

On the other hand, team B used the model for discussion in the middle of a process and actively participated in claim and argument at the end. In other words, team B

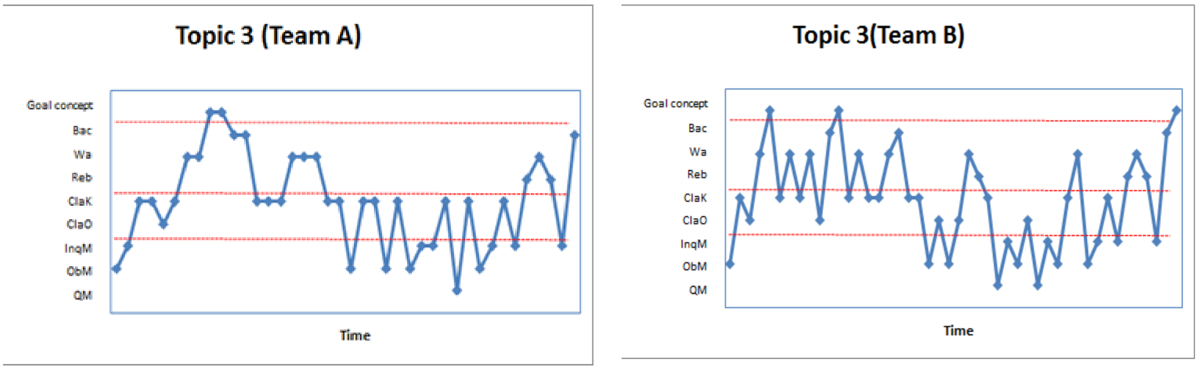

Figure 10. Two teams' time sequential distribution of argumentation about topic 3.

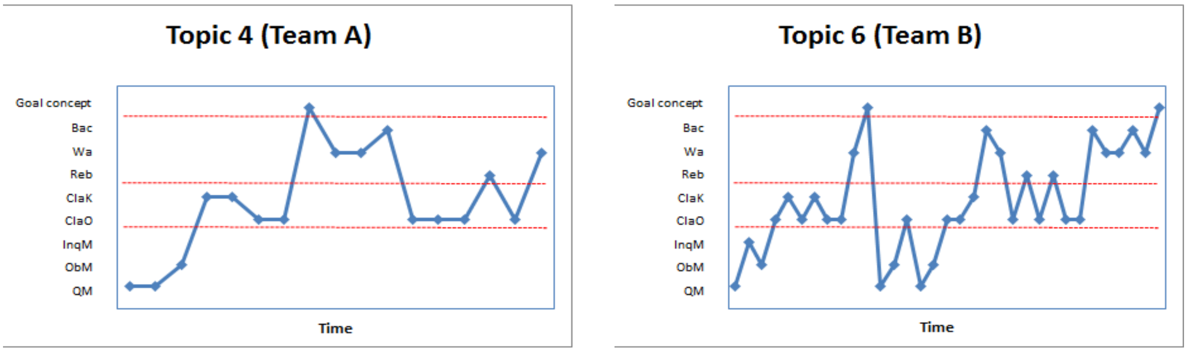

Figure 11. Two teams' time sequential distribution of argumentation about topic 4.

used the model actively discussing the virtual situations where a distance of dent mark was kept the same. As a result, they appropriately deduced that retrograde motions were not to be observed if the revolutionary speed was maintained the same. Considering that team B who ended up understanding the cause of the retrograde motions of Mars after going through model exploration, explanation of cause and argument, we may argue that team B showed more successful modeling in overall than team A.

Distribution of Concept Types about the Reason of Retrograde Motion of Mars

According to the result of analysis on responses after administering the of apparent motion of Mars both to the experimental group and comparison group, four types such as naive framework, incorrect concepts, incompletely correct concepts, and correct concepts were derived. Examples of them are as follows in Table 2.

The results derived from investigating the frequency and ratio of each type to compare the conceptual understanding of the experimental group and comparison group after the class are as follows.

As presented in Table 3, the ratio of students with the lowest understanding level of naive framework was revealed to be 13.3% in the comparison group that was higher than the experimental group (3.2%). As for the causes of retrograde motion of Mars, there were many cases related to the rotation or rotation axis of the earth. In addition, there were students that had an incorrect concept of how Mars was blocked by the sun. The ratio of students with incorrect concepts was turned out to be 28.4% in the comparison group that was higher than the experimental group (14.5%). Among the alternative concepts of this type, an example of explaining is "the planet is not fixed on the particular position in the celestial sphere but keeps changing". This explanation has mentioned general characteristics of a planet because of not understanding the causes of retrograde motion. In addition, there was an explanation

Table 2. Type of concepts about the reason of retrograde motion of Mars

Type	Characteristics	Examples
Type 1	naive framework	- It might be blocked by the sun or to be seen all day long since we saw Mars from the earth. - It might be because the earth is rotating and also revolving. - It seems to be much influenced by the sun. - It might be because the rotation axis of the earth is tilted.
Type 2	incorrect concepts	- It might be because that the distance seen from where we saw and the actual distance to Mars is different. - Because planet is not fixed on the particular position in the celestial sphere but keeps changing. - Because the changes in revolutionary orbit of the earth and the one of Mars are different. - Because of an eccentricity difference.
Type 3	incompletely correct concepts	- Because the revolution of the earth and Mars is different. - Because the revolution speed of the earth and Mars is different - Because the revolution distance of the earth and Mars is different - Retrograde motion occurs since people see Mars from the earth - When seeing other trains running slower than the train we are currently taking in the same direction, they seem to run backwards
Type 4	correct concepts	- Because the revolution speed of Mars is slower than the earth - Because the revolution speed of the earth is faster than Mars - Because the revolution period of Mars is longer than the earth - Because the revolution period of the earth is shorter than Mars

Table 3. Frequencies and percentages of each type of concepts about the reason of retrograde motion of Mars

	Type	Characteristics	Experimental group(n=62)		Comparison group (n=60)	
			Frequency	Percentage	Frequency	Percentage
reason of Mars retrograde motion	Type 1	naive framework	2	3.2	8	13.3
	Type 2	incorrect concepts	9	14.5	17	28.4
	Type 3	incompletely correct concepts	23	37.2	21	35.0
	Type 4	correct concepts	28	45.1	14	23.3
		total	62	100	60	100

how the observed distance of Mars and the actual distance of Mars were different. This is also an example of not recognizing the revolution period and the revolution speed of as a cause of retrograde motion. There was a student who was limitedly focusing on the revolutionary orbit and explaining how changes in the revolutionary orbit of earth and Mars were different. As a similar alternative, incorrect concepts include an example of explanation with orbit eccentricity, indicating how long the elliptical orbit was. According to such a result that the ratio of naive framework and incorrect concepts was significantly higher in the experimental group, it seems that the comparison group applied with traditional lecture was in a disadvantageous condition in building scientific mental model about the retrograde motion of Mars than the experimental group carried out modeling-based learning.

As for incompletely correct concepts, they suggested partially scientific explanation of Mars retrograde motion with the difference of revolution period or revolution speed of Mars and the earth, and the concept of relative speed. The ratio 37.2% in the experimental group was higher than the comparison group (35.0%). Therefore, it seems that the effect of modeling-based learning was positive. Most of the students in this category have explained that the difference of the revolution period or revolution speed of Mars and earth was the cause of Mars retrograde motion. This was classified into the incompletely correct concepts since they did not compare whether the value of period and speed was bigger than other object. Some students have explained that it occurs as the revolution distance was different between Mars and earth. Since this indirectly included the concept of revolution period and revolution speed, they were relevant to incompletely correct concepts. Students in the experimental group have explained the reason of retrograde motion by applying the concept of relative speed with a faster train as the earth and a slower train as Mars.

Correct concept type is a case that the cause of Mars retrograde motion was scientifically explained. Namely, students had correct concept properly compared the revolution period or revolution speed of Mars and earth. The ratio of the experimental group (45.1%) was higher than those of comparison group (23.3%). Therefore, it shows that the effect of modeling-based learning was positive.

CONCLUSION AND SUGGESTIONS

This study was intended to present an analytic framework for coding students' dialogic scientific argumentation in the modeling-based learning environments. Argumentation analytical framework of the TAP(Toulmin, 1958) was referred to in this study that we developed the argumentation analytical tool by primarily analyzing the full transcripts of modeling-based learning. As for parts we presented a different view, after re-discussing and negotiating them, finally confirmed eight coding components in three categories. In the model exploration category of coding components, question about the model (QM), observation on the model (ObM), and inquiry method (InqM) were included. In the claim category, claim based on observation (ClaO) and claim based on knowledge (ClaK) were included. In the reasoning category, rebuttal (Reb), warrant (Wa), and backing (Bac) components were included for supporting and justifying the claim. The proposed analytic framework appears to provide a useful set of tools for analyzing the frequency of argumentation components and time sequential pattern of the argumentation. Furthermore, it was viable to identify how learners interact with each other for modeling learning and which argumentation patterns are more useful in creating scientific concepts of the apparent motion of Mars.

In this study, some students observed model but was only able to explain it not based on observation but on prior knowledge regarding motions of the sun and Mars. Contrarily, other students made an attempt to explain the movement direction of the sun and Mars based on the result of observation and successfully modeled them. Also, higher frequency of observation on the model the more statement of rebuttal, warrant, and backing in the reasoning category as well as the more claims based on observation. For instance, after deducting the reason why an angle between interval of groove marks on the revolutionary orbit and the center of the sun was different, a conclusion was made that the revolution speed of the earth was higher. This is a process of understanding the causes of retrograde motions of Mars after exploring the model, explaining the causes and disputing them. It is a case of successful modeling-based learning that abductive reasoning was properly made in an attempt to explain the causes of model exploration.

Research evidence(Erduran et al, 2004) suggested the presence of a rebuttal as a significant indicator of quality of argumentation since a rebuttal and how it counters another's argument forces both participants to evaluate the validity and strength of that argument. They focused on those instances where there was a clear opposition between students and assessed the nature of this opposition in terms of the strength of the rebuttals offered. In this sense, a variety of model exploration is essential for productive argumentation which includes reasoning process added with the claims. Precisely, the rebuttal, warrants or backings offered were in direct evidence of a higher level modeling-based learning. In addition, the results indicate that claim based on prior knowledge was shown more frequently than claim based on observation when students had difficulty in connecting between the results of observing and the related scientific concepts. Therefore, teachers need to explain it in relation to scientific concepts and the model at this moment.

The time sequential pattern of the argumentation traced by focusing the students' interaction in small group conversational discussion. According to the results, a group repetitively provided the same opinion with other students, while other group actively interacted with other students by exchanging opinion with one another. For instance, a group was asked about the model and suggest exploration methods and observed the model again. Afterwards, when providing claim based on them, they responded with rebuttal or warrant and ended up reaching to the ultimate conclusion. Considering this argumentation pattern, we could argue that students engaged in the process of building and testing models of physical systems based on the representation of the underlying causality of the systems by process of argumentation frequently cross all three categories. It is an empirical evidence of the earlier study comparing relation-based thinking with model-based thinking in science (Fretz et al., 2002). In relation-based thinking in science, students decompose the physical system under study into smaller easily identifiable parts and explore how the system's parts are causally related with each other. In other words, in relation-based thinking students identify the physical objects involved in the phenomenon to be modeled, and possibly their physical behavior. Alternatively, in model-based thinking students assumes that a network of interconnected observable features of the system with the explicit description of their relationship with a representation of the system parts' underlying causes. Consequently, a process of argumentation frequently cross all three categories is regarded as an effective pattern of modeling-based learning.

Meanwhile, according to the result of the concept survey both to experimental group and comparison group, four types of the students' conceptions of the apparent motion of Mars were found in the study; naive framework, incorrect concepts, incompletely correct concepts, correct concepts. It was revealed that students with a correct conception tended to explain that the cause of retrograde motion of Mars was scientifically, namely, it is of a case that correctly compared the revolution period or revolution speed of Mars and the earth. As for incompletely correct concepts, they have only referred to the difference of period or orbital velocity between Mars and the earth without comparing whether the value of period and speed was bigger between them. Some students have incorrect concepts limitedly focusing on the orbit of revolution and explaining how changes in the revolutionary orbit of the earth and Mars. As a similar alternative, incorrect concepts include an example of explanation with orbit eccentricity, indicating how long the elliptical orbit was. Contrarily, students with a naïve conception perceived the causes of retrograde motion of the Mars, related to the rotation or rotation axis of the earth.

According to the results of comparing the experimental group and the comparison group the ratio of students with naive framework and incorrect concepts in the comparison group was higher than those of experimental group. On the other hand, the ratio of students with incompletely correct and correct concepts in the experiment was higher than those of comparison group. Therefore, it shows that the effect of modeling-based learning environment was positive in terms of that the dialogic scientific argumentation enables students to generate competing explanations for a given phenomenon, and then provides them with an opportunity to examine and discuss these explanations based on the model related discourse. .

Consequently, productive modeling argumentation makes it available to change an instable mental model of students to a scientific mental model. In addition, argumentation activities make it feasible to evaluate and modify the model to constitute more appropriate model while abandoning inappropriate one (Bottcher & Meisert, 2011). Students make an effort to explain and justify a personally established model so that other students are able to understand in social aspects. Therefore, explanatory model can be reinforced through more logistic reasoning process. This is also meaningful in that it is intended to learn not only model itself but also process of creating and asking about the created models. The results of this study should be valued as empirical evidence that discourse analysis can provide the tools for understanding how modeling can be improved. In subsequent studies then, we intend to investigate how teachers encourage their students to justify their claims and provide their own warrant and rebuttal in details.

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Appendix 1. Example of analysis on the argumentation regarding the causes when the Mars strip is made to be bulged out in the model

Coding	Student	Discourse
QM	E	Where in the model does it bulged out?
ObM	B	(Pointing out the Mars strip) One side is facing up.
ClaO	C	This is something like Zodiac. One side of the Zodiac is going up.
InqM	D	(Pointing out the paper on the floor) Then, this part should be higher than that.
ClaK	A	Model is the reduced version of the space, so it is meaningless to increase the height of floor.
ObM	B	Mars strip is bulged out a little bit more than the one of earth.
ObM	E	I can see the routes we pointed with red color.
QM	C	Has the sun moved?
ObM	E	The sun has moved like this.
ClaO	B	The sun has moved when seen from the earth.
ClaK	A	Zodiac was where the sun moved by.
QM	E	What do we call the one shown in black strip?
ObM	B	What was in black was not a straight line.
ObM	C	What was in black was in ring shape.
ClaK	C	Let's call it revolutionary orbit of the Mars.
QM	D	Why is it revolutionary orbit of the Mars?
ClaO	C	Touching the vertically standing strawboard of the celestial sphere) Because it is located outer than that.
Reb	B	This is not the revolutionary orbit of the Mars (Touching the vertically standing strawboard). This is the revolutionary orbit of the Mars.
ClaO	F	(Touching the strawboard of the celestial sphere). If I saw the Mars from the earth it moves like this.
Wa	A	When we look at the Mars from the earth, it moves like this in the celestial sphere.
Bac	B	It is like when I look at the house near to me moves when we see the landscape from a train.
ClaO	F	Aha! This is the apparent motion of Mars.
QM	D	Why is the Mars strip bulged out?
ObM	B	The position of Mars is higher right here than earth.
ClaO	B	The position of Mars is tilted compared to earth.
Goal Concept	B	Because the revolutionary orbit of Mars is tilted compare to earth.