DOCUMENT FEATURES IN PHYSICS TUTORIALS TO PROMOTE COLLEGE STUDENTS' USE OF ARGUMENTATION

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(Received: 10.03.2019, Accepted: 23.05.2019)

Abstract

This study explored how research-based physics tutorials help students use argumentation in a small group-work activity. The participants were four first-year non-major physics students taking algebra-based introductory physics course in an urban university in the southeastern region of United States (US). The content analysis was conducted to select tutorials with specific features on Kinematics and Dynamics subjects from "Tutorials in Physics Sense-making" (Elby et al., 2007). Data included video-recordings of students' group discussions. Transcriptions of student talk were analyzed using modified Toulmin's argumentation layout (McNeill et al., 2006). The results indicated that students could engage in argumentation while working on the selected tutorials. However, they mostly provided simple arguments including "Evidence-Claim (EC)" pairs; their use of complex arguments was rare. In addition, students' arguments across three tutorials were categorized into three groups: interpretation of graphs, interpretation of motion, and interpretation of equation. Students mainly made evidence-based explanations referring to the equation if the question included a problem with concrete numerical values. If the activity required students to predict the motion of an object and make connection to the physics concepts, students' arguments were mainly about the interpretation of motion and its graphical representation. This study provides instructional implications and suggestions for further research to promote teaching and learning through argumentation in physics classrooms.

Keywords: Physics education, physics tutorials, argumentation, group discussions

INTRODUCTION

Physics Education Research (PER) groups aim to overcome the challenges of traditional instruction by developing new instructional methods and materials to promote more effective teaching and learning process in physics classrooms (Docktor & Mestre, 2014). Most of new instructional strategies and course materials are designed to facilitate students' active participation in order to engage them in the practices of inquiry and discourse including asking questions, collecting and analyzing data, drawing conclusions, and communicating results, identifying assumptions and alternative explanations and using the logical thinking (National Research Council (NRC), 2012). These innovative resources aims to enhance students' involvement in cognitive, social, and material work of science that scientists usually do (Duschl, 2008; Ford, 2015).

As a core scientific practice, scientific argumentation is considered as the significant component of scientific literacy (Cavagnetto, 2010; Duschl, 2008; McNeill & Krajcik, 2008) that learners can practice the experiences of the scientific community through knowledge construction, critique, and justification (Berland et al., 2016). During a collaborative task, students are active participants of the learning process (Campos, Silva, Tecpan, & Zavala, 2016); they can express and evaluate their own and peers' thinking, reconstruct their ideas through reflection, and promote scientific reasoning and conceptual understanding (Osborne, 2010). Working alone does not provide opportunities to make their understanding clear to others and evaluate the validity if the ideas; but, through group work, students can make the conceptual ideas available, and discuss and experiment these ideas in the social plane.

This study explored students' arguments while they were working on physics tutorials (Open Source Tutorials in Physics Sense-making) that were designed to focus on concept building and development of scientific reasoning in small groups (Elby et al., 2007). Scherr and Hammer (2009) framed students' group work discussions while working on the tutorials to understand what was going on in a small group interaction that could maintain a sense of activity as argumentative (Berland & Hammer, 2012). Their findings indicated that working on tutorials resulted in enhanced conceptual understanding. However, Rebello, Barrow, and Rebello (2013) found that students had difficulty in constructing scientific arguments since they were used to solve physics problems through novice methods such as formulaic approaches. There is still a question of whether these research-based tutorials promote the use of argumentation to enhance students' conceptual understanding in physics classrooms. The author, thus, conducted a study to explore the basic features of research-based physics tutorials and understand how these resources help students' use of argumentation in a small group-work activity. Specifically, the study investigated the answers to the following research questions:

1) What are the basic document features used in research-based physics tutorials?

2) How do the basic features of the physics tutorials facilitate the use of argumentation in small groups?

THEORETICAL FRAMEWORK

Argument as A Product

Toulmin's model of argumentation is widely used to identify the basic components of an argument as a product (e.g. Erduran, Osborne & Simon, 2004; Sampson & Clark, 2008). In the *Uses of Argument* (Toulmin, 1958), Toulmin discusses the process of argumentation as making good claims to get the ideas clear and justifying them by evidence. The features of the arguments can change based on the nature of the cases, assessment, criticism or justification made to support or refute the assertions. Toulmin's argumentation framework has six elements: claim, data, warrant, backing, rebuttal, and qualifier. McNeill and colleagues (2006) modified the Toulmin's Argumentation Layout (Toulmin, 1958) to "create an instructional model of scientific explanation that is usable by a large number of teachers and students" (p. 157), and their model included three components: claim, evidence, and reasoning. In this study, the author adopted the scientific explanation model to assess students' explanations and also focused on students' rebuttals that present opposing views to the arguments (McNeill et al., 2006; Toulmin, 1958) because use of rebuttals and providing justification are the features of complex arguments (Erduran, Simon, & Osborne, 2004). The claim is defined as the assertion or conclusion for a specific situation; the evidence is the interpretation of data to support a given claim; the reasoning is defined as the justification to explain why evidence supports the conclusion; the rebuttal makes a claim about why alternative claims are incorrect (McNeill et al., 2006; Toulmin, 1958). Previous research such as Bell and Linn (2000), Reiser (2004), and Jonassen et al. (2009) claimed that students could provide better arguments if they were provided the expectations for the elements of an argument. These studies scaffolded the use of components of an argument through specific questions that could encourage students to link the answers of questions to the data that they obtained through the experiments or observations. However, in this study, the author did not aim to guide the students' arguments with particular prompts, phrases, or questions. The study aimed to understand how students engaged in argumentation without any scaffolding.

Argument as A Process

Argumentation also supports students' involvement in the social aspect of science, in which learners construct and revise knowledge claims through interacting with others to learn a task together. In this process, students talk about science concepts, listen to alternative ideas, and critique, build on, and refine each other's explanations (Ford, 2012; Jimenez-Aleixandre & Crujeiras, 2017; Sampson, Enderle, & Grooms, 2013). Through participating in a dialogic interaction with their peers, students can experience the construction and justification of knowledge claims as well as convincing the others on the validity of their claims as the practices of scientific community.

METHODS

Participants

The participants were four first-year non-major physics students enrolled in "Introductory Algebra-Based Physics-I" classes at an urban university in the southeastern region of United States. Students were recruited through visiting their classrooms and asking for their voluntary participation for the study. Students did not receive course credit for their participation or their participation to the study did not influence their course grades. Participants were two male and two female students from Department of Biology, who were taking an algebra-based physics course; and their grades in the course were at the same level and around B. Even though they covered the same concept in the classroom, they did not work collaboratively on the selected tutorials before. The study was conducted outside of a regular lecture that students came together to work on each tutorial in a small group in different weeks of the fall semester. Each tutorial session lasted two hours and started with an introduction about the purpose of the study.

Data Collection and Analysis

Selection of tutorials. Research-based curriculum materials aim to help students construct their knowledge, improve conceptual understanding, make sense of concepts in a qualitative way, and make connections to the real-world situations through discussions with group members (Docktor & Mestre, 2014). "Tutorials in Physics Sense-making" is a set of research-based physics tutorials developed by the University of Maryland to focus on both concept building and development of student epistemology (Elby et al., 2007). Due to the objectives of these tutorials concerning the development of scientific reasoning, the author explored the document features of each tutorial via content analysis to understand how a specific feature can promote the use of argumentation during group discussions.

Table 1*. Tutorials and the most common features*

Kinematics & Dynamics	**Features (Frequency)**
Interpreting graphs and equations	Thinking (15), interpret (18), graph (14)
Competing arguments: Backwards acceleration	Argument (10), predict (20), mistake (18), graph (27), experiment (16)
Reconciling common sense and Newton's laws	Group (9), Intuition (13), Explain (7)

For document features, a summative approach to qualitative content analysis has been done to define the quantity of certain words and to understand the underlying meanings of words or objectives of using a specific word for a physics problem (Hsieh & Shannon, 2005). The author checked the frequency of the use of a target word or expression on the tutorials. The researcher has chosen the target words or expressions by looking at the common words that can facilitate students' social and cognitive behaviors in a group work. The seven tutorials from "Tutorials in Physics Sense-making" on Kinematics and Dynamics subjects were analyzed in detail.

Based on the results of the analysis, the author selected three tutorials that could encourage students' engagement in scientific practices. For example, these tutorials emphasized the development and use of models through generating pictorial, graphical, and qualitative representations of the concepts as an expert ability in solving physics problems (Meltzer, 2005). Additionally, these tutorials supported planning and conducting the scientific investigations through asking questions, developing hypotheses, collecting and analyzing data, and making scientific explanations to argue about the validity of their findings (NRC, 2012). Corresponding words for selected three tutorials are represented on Table 1.

Table 2. *Definitions of the structural elements of an argument (McNeill et al., 2006; Toulmin, 1958)*

Component	**Definition**
Claim	The assertion or conclusion for a specific situation
Evidence	The fact relied on to support a given claim
Reasoning	The justification to explain why evidence supports the conclusion
Rebuttal	The claims about incorrectness of a stated claim

Group-work discussions. Before the study, informed consent forms were obtained from participating students for videotaping the sessions. The students participated in three tutorial sessions for two hours each, and their group-work discussions were video-recorded to explore how specific features of the physics tutorials facilitated the use of argumentation. Verbatim transcriptions of group discussions were also used as data sources to analyze students' discussions based on modified Toulmin's Argumentation Layout (Toulmin, 1958) including claim, evidence, reasoning, and rebuttal components (McNeill et al., 2006; Toulmin, 1958). The definitions of the elements of an argument structure are provided on Table 2. The analysis focused on students' use of argumentation while working on physics problems rather than focusing on whether students reached the correct solutions.

Two researchers (the author and a physics education researcher) coded students' group discussions using the analytical framework on Table 2. In order to resolve the ambiguities in the coding process, the researchers looked for specific indicators defining the claim, evidence, reasoning, and rebuttal. For instance, "so, therefore, for this reason, that's why, that means" were used as the indicators of a claim, whereas "since, because, cause, if … then" were used as the indicators of evidence (Asterhan & Schwarz, 2009; Erduran, Osborne, & Simon, 2004). An opposition sentence including both data and claim was coded as a rebuttal (Toulmin, 1958). By referring to study of Kelly, Druker, and Chen (1998), the researchers did not attempt to identify robust measures in reporting the inter-rater reliability, rather they assessed the relative plausibility of an interpretation by comparing with the alternative interpretations. Researchers coded the transcriptions of students' group work independently and jointly. The entire transcript was coded independently, and then the researchers negotiated the common, mutual agreement of the understandings for the features of students' arguments.

RESULTS

After analyzing students' group discussions based on argumentation framework, one way to understand the function of the document features was looking for the dialogues that students mostly engaged in the use of argumentation with appropriate physics knowledge. The researcher examined students' arguments while they were working on the tutorials with different features. Tutorial-1 focused on the interpretation of graphs and equations; Tutorial-2 focused on the prediction, experimentation, and discussion; Tutorial-3 focused on intuition. Students' use of specific elements of an argument was compared across the tutorials to understand how students framed their discussions and what helped them argue. Students' discussions were coded considering the combinations of the elements of an argument. The arguments included "Evidence-Claim (EC)", "Evidence-Claim-Rebuttal (ECR)", "Evidence-Claim-Reasoning (ECRsn)" or "Evidence-Claim-Rebuttal-Reasoning (ECR-Rsn)" components. In addition, the arguments were also classified into three categories based on what made them argue: *Interpreting graph, interpreting equations, and interpreting motion*. Figure-1 represents the frequency of students' use of argumentation for each tutorial.

Tutorial 1: Interpreting

The first tutorial was related to "Interpreting graphs and equations." The researcher examined how drawing and interpreting representations helped students develop an understanding of the concepts and explain their understanding via argumentation. The results of analysis showed that students' arguments focused on the interpretation of graphs, equation, and motion. The students occasionally made extended arguments by providing three or more evidence-claim (EC) pairs, but they rarely used evidence-claim-rebuttal (ECR), evidence- claim-reasoning (ECRsn) or evidence-claim-rebuttal-reasoning (ECR-Rsn) combinations. These results are also represented on Figure 1.

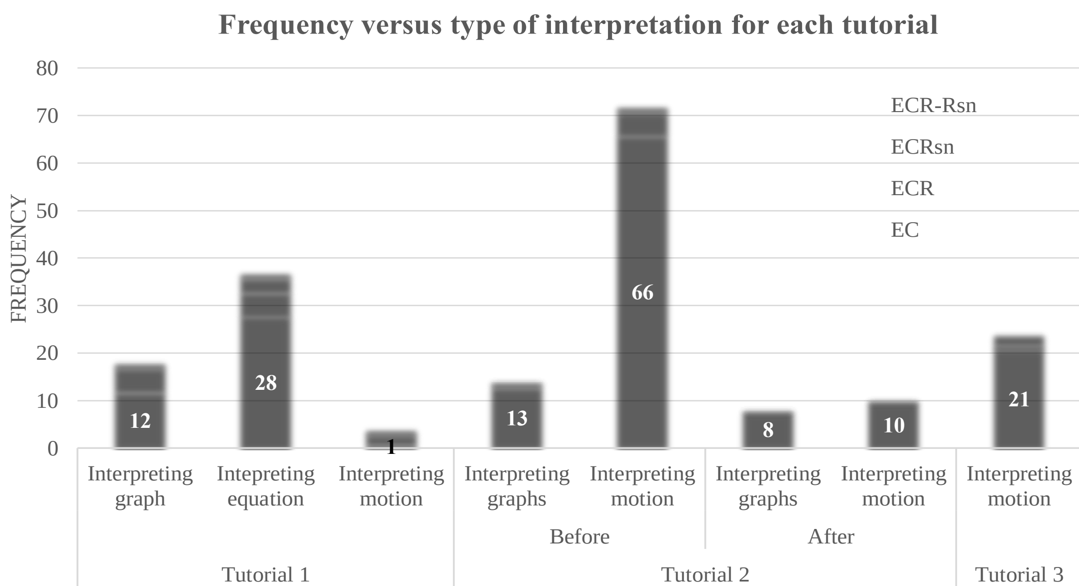

Figure 1. *Frequency of students' use of argumentation for each tutorial*

Here is an example from a group conversation on a problem on Tutorial-1: Students were required to evaluate the solution of a given problem that is about an object moving with uniform acceleration with an initial position of 10 cm and at position 24 cm after 2 seconds. Students were expected to evaluate the solution about the question, "how much longer will it take the object to travel 70 cm farther?" (Elby et al., 2007). During the discussion, students stated:

Student-1: Is the student's solution correct? I would say so. Yes.

Student-2: What is your reasoning for this? I don't know how to explain it

Student-1: Acceleration equals velocity over time [REASONING], right? This is already velocity over time, so technically, it is already acceleration [CLAIM]. You are using acceleration since you have the velocity [EVIDENCE]. So, you use acceleration and velocity to find time [CLAIM]. So, you should say they are equal to each other [CLAIM] because they will be the same thing [EVIDENCE]. Because acceleration is constant [EVIDENCE].

In the above dialogue, students were asked to interpret the solution of a problem and explain whether it was correct or not. Student-1 (S1) was arguing about the meaning of equations, which constituted a symbolic form of abstract concepts. She made a connection between the equation and its physical meaning. S1 described the equation of acceleration as, "Acceleration equals velocity over time," in order to justify her former claim, "The student's solution is correct." By referring to the question, S1 was trying to explain that acceleration was constant and that's why both sides of the equation should be equal to each other. She was providing "evidence-claim" pairs while making general explanations about the concepts, but she could also explain how the evidence and claim were related to each other by referring to the scientific principles such as saying, "*Acceleration equals to velocity over time*." The students couldn't use higher patterns of argumentation, such as rebuttals. The student was making explanations based on the formal understanding of physics, such as an abstract form of equations, instead of experiment-based solutions. The results of this example suggested that it was difficult for students to provide complex arguments when they dealt with the abstract form of mathematical equations of physics concepts.

Tutorial 2: Prediction

In the second tutorial, students were provided four situations (Elby et al., 2007) that could be observed in a real-life situation:

1) Releasing a cart from rest on a ramp, with the motion detector at the top,

2) Releasing a cart from rest on a steeper ramp, with the motion detector at the top,

3) Attaching a "brake" to the cart by placing it on a level surface and giving it a brief push away from the detector,

4) The motion detector sits at the bottom of a ramp and cart starts near the bottom.

After giving it a brief push up the ramp, the cart reached its peak and rolled back down. In these situations, students individually made predictions, and then made comparisons in-group before testing their predictions through experimentation. This arrangement facilitated group discussions and encouraged students to express their own ideas. While analyzing students' group discussions, the author focused on students' argument construction by noticing when they made predictions and when they provided evidence to support their claims from the experiment and evaluated or changed their opinion after the experiment. Students' group discussions showed that students' physics reasoning was developed while the complexity of the questions or situations increased. Group discussions were shaped based on the attitudes of the group members because students, who were willing to share their ideas in a collaborative manner, participated more in the discussions and they learned to make better arguments.

The analysis of students' group discussions showed that students usually made arguments while interpreting the motion of visible and concrete events. Students mostly provided evidence-claim (EC) pairs and rarely provided evidence-claim-rebuttal (ECR) combinations. The researcher classified students' argumentation under two categories based on what made students argue: Interpreting the graph, interpreting the motion. Figure-1 also represents the students' use of argumentation for Tutorial 2.

Here is an example of students' elaboration to the prediction part for "attaching a brake to the cart" (the third situation). The student tried to make a clarification by elaborating on the explanations of other group members that were not including justification for their claims. He justified his reasoning by providing evidence as below:

> *Student 2 (S2): Um, so, acceleration increases (CLAIM) when you initially push it (EVIDENCE), but then it starts to slow down (CLAIM) because um, we kind of haven't really learned this at this point yet, but friction works against the cart (EVIDENCE). So, acceleration might be going towards that way (shows left) (CLAIM) as the cart goes this way (shows right) (EVIDENCE) (CLAIM)… So, acceleration has to be going negative (CLAIM)…*

In this passage from Tutorial 2, students made a connection between the motion and its graphical representation. Student-2 (S2) described an observable feature of the cart's motion by saying that the cart "starts to slow down," and argued that this slowing down resulted from friction working against the cart. S2 went on to talk about the acceleration of the cart, which he could see on a computer-generated graph that was tied to his motion sensor. S2 had previously made a prediction about "the velocity and acceleration vs. time graphs" as "acceleration would be constant." Here, he was elaborating on a prediction he made previously, when he said that acceleration would be constant. He was trying to explain an observation, which he made and conflicted with his prediction - namely, that acceleration changed as the cart was pushed and then released. Thus, S2 was talking about observable, concrete features of the cart's motion as well as the graphical features. He argued in response to an observation that contradicted his earlier prediction in the first situation.

Tutorial 3: Intuition

"Tutorial 3: Reconciling Common Sense and Intuition" is prepared in order to assist students to utilize their common-sense knowledge in an epistemological sense (Elby et al., 2007). Students are expected to use their intuition by refining their ideas that motion requires a net force to initiate the motion rather than treating it as a completely wrong idea (Elby et al., 2007). Students think about a situation in which a boy is pulled upward at constant speed and face a contradiction between Newton's second law and their common-sense idea that the rope should have a greater force than gravity (Goertzen, Scherr, & Elby, 2009). The purpose of this activity is to assess students' common-sense ideas and help them make distinction between the force to initiate a motion and the force to maintain a motion.

The results of the analysis showed that students usually made arguments on interpreting the motion on abstract events while making connection between force, acceleration, and velocity. Their misconceptions about the force to initiate and maintain the motion also made them argue. In this study, students mostly provided evidence-claim (EC) pairs, and rarely evidence-claim-rebuttal (ECR) and evidence-claim-reasoning (ECRsn) components. Figure 1 represents the frequency of students' use of argumentation for Tutorial 3.

Here is an example how Student-4 (S4) makes use of argumentation while refining their common-sense knowledge:

S4: I mean either we can get technical and go by … what the like the wording is (CLAIM), because it says, "as the child is pulled upward at constant speed." It didn't say like, like as you begin to pull the child up (EVIDENCE). Cause I understand when you guys say greater, cause as you, like it has to start moving before it like reaches constant speed (EVIDENCE), so that's how you guys say greater, but if you go by when it's at constant speed (EVIDENCE) then it's goanna be equal (CLAIM)(CLAIM).

In this passage from Tutorial 3, students discussed about the misconception that tutorial addressed as an object needed a net force to move upward. Students referred to Newton's Second Law using "F= ma" and considered that the upward force from the rope was equal to the downward force from gravity, so "the net force on it is zero." Then, S4 continued talking about the initial net upward force before reaching the constant speed. S4 was elaborating on group members' explanations and arguing that the upward force should be greater than 250 N to initiate the motion; but then it would be equal to 250 N to have constant speed. She was trying to explain her common-sense knowledge by saying that initial force should be greater than boy's weight. Here, students' common-sense knowledge made them argue about a motion that was observable in an imagined situation. In the following part of the tutorial, this argument helped them refine their intuition, as "a net force is needed to initiate or change motion, but not to maintain the motion."

DISCUSSION AND CONCLUSIONS

This study explored the students' use of argumentation while working on research-based physics tutorials, which aimed to enhance students' active involvement and develop scientific reasoning through collaboration in physics classrooms. Three tutorials were selected based on their features, which could engage students in different scientific practices such as developing and using models, planning and carrying out investigations, and making scientific explanations (NRC, 2012). The analysis of students' group discussions on each tutorial demonstrated that students could build scientific arguments during a collaborative activity through elaborating on each other's ideas. Most of the arguments were simple across the tutorials including "evidence-claim (EC)" pairs; students rarely provided complex arguments with "evidence-claim-reasoning (ECRsn)" or "evidence-claim-rebuttal (ECR)" combinations. These results indicated that research-based physics tutorials, which were designed to support peer instruction and collaboration (Docktor & Mestre, 2014), can facilitate students' use of argumentation. However, students provided simple arguments; students had difficulty in constructing complex arguments through making alternative explanations and critiquing scientific ideas (Ford, 2012). Students' arguments lacked the complexity without any type of scaffolding such as guiding questions or prompts (Bell & Linn, 2000; Ford, 2012; Jonassen et al., 2009; Rebello et al., 2013). Argumentation prompts for using the specific elements of an argument such as claim, evidence, and reasoning components or for constructing and evaluating the scientific views could enhance the quality of students' arguments (McNeill et al., 2006; Rebello et al., 2013).

The content of the students' arguments while working on the tutorials on Kinematics and Dynamics subjects was classified into three categories: Interpreting graphs, interpreting motion, and interpreting equation. In particular, the abstractness of the subject matter strongly influenced the claims in students' arguments. For example, in the first tutorial, the abstractness of the equation, in other words, symbolic form of equations made students argue about the meaning of the physics concept. In addition, during the second tutorial, students made evidence-based explanations while making predictions on the motion of an object. Their observations helped them make comparisons between their predictions and concrete features of the cart's motion. Moreover, students' use of common-sense knowledge in the third tutorial encouraged them to think and make connections between abstract events and physics concepts such as force and acceleration. This result was supported by the literature. De Cock (2012) also argued that students learn abstract concepts through using and coordination different forms of representations including a graph, picture, formula, or diagram. She found that student performance could differ based on the representation format; in her study, students used equations in their arguments when they were given concrete numerical values related to concepts. Similarly, in this study, when students were provided an equation, they tended to argue more about the meaning of the equation and the solution of the physics problem with the given numerical values. However, if students were not required to consider the equation, they focused on the verbal and graphical representation of the motion.

Additionally, inquiry-based activities encourage students' engagement in scientific practices (Hofstein & Lunetta, 2004; Sampson et al., 2013). During the second tutorial, after students made the predictions, they worked on a hands-on activity, which allowed them to be active participants of their learning process through asking questions, making scientific explanations, collecting and analyzing data, and engaging in argument from evidence (NRC, 2012; Sampson et al., 2013). Moreover, the second tutorial focused on "Predict-Experiment-Discuss" cycle similar to "Predict-Observe-Explain" strategy suggested by Osborne, Erduran, and Simon (2004) to integrate argumentation in science classrooms. Predictions promoted students' thinking and interpretation of the motion of a cart before the observation. Students made arguments about the motion of an object and its graphical representation based on their prior knowledge, and then, they revised their conceptions from the prediction part through experimentation and discussion. This result is also supported by the literature. Berland and McNeill (2010) discussed that teacher or curriculum designers could facilitate the argumentative products by developing norms to support student-student interactions or student-teacher interactions to foster engagement in scientific argumentation. The "predict-discuss-experiment" cycle in the second tutorial provided a context to support student engagement in the dialogic process and help them make their ideas available to others to evaluate and question different ideas to make revisions and reach a consensus (Berland & Reiser, 2009). Prediction part helped them reveal their prior knowledge and reflect on each other's ideas about scientific conceptions and phenomena through discussion. After that, experiment or observation part allowed students to observe the situation and revise their answers.

In this study, research-based tutorials could promote students' use of argumentation including mostly "evidence-claim" pairs. The abstractness of the concepts enhanced students' use of argumentation via different representational formats including equations, graphs, or verbally. In addition, "Predict-Experiment-Discuss" cycle of the second tutorial supported the argumentation process. These results suggested that the use of argumentation could depend on the feature and nature of the task (Rebello et al., 2013). Further research should focus on enhancing the quality of the arguments by providing specific prompts as a guide to construct the claim, evidence, reasoning components for their arguments and to critique each other's arguments through appropriate rebuttals.

Moreover, this study was confined to four non-major physics students' discussions in three research-based tutorials, which supported students' collaborative work through making evidence-based explanations to develop an understanding of cognitive, social, and epistemic basis of science. However, sample size was a limiting factor to generalize the results. Further research is necessary to explore the students' use of argumentation while working on other physics tutorials or curricular resources focusing on different physics concepts. Additionally, the data collection was limited to students' group work discussions. Different forms of data collection, such as student interviews, are necessary to explore student reasoning on science concepts and understand the ways that support students' engagement in argumentation during group discussions.

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