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The Relationship Between Chinese Students' Subject Matter Knowledge and Argumentation Pedagogy

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Science education in China is Subject Matter Knowledge (SMK) oriented in that SMK understanding is the major benchmark to assess students' achievement in science learning. Such an orientation causes students to overemphasize the memorization of SMK and neglect other indispensable components of science, such as scientific attitudes and research skills. The central government in China launched an educational innovation known as New Curriculum Reform in 2003. Considerable progress has been made in the past 11 years in regard to theoretical understandings and administrative priorities, but little progress has been made in terms of classroom instruction and scientific literacy cultivation at the secondary level. Under the pressure of nationwide standardized exams, any educational innovations are unlikely to be accepted unless there is robust evidence suggesting their efficacy in promoting students' achievements on exams, or even attempted unless teachers are assured such attempts will not negatively impact such achievement. Argumentation-integrated curriculum is one such innovation. Scientific argumentation is an essential scientific activity that leads to the development of an explanation based on empirical evidence. An initial foundation of SMK, in terms of the necessary background knowledge, is considered by many to be a vital component of argumentation and an enhanced SMK is one of the intended products of argumentation. The purpose of this sequential explanatory mixed methods study was to investigate the relationship between Chinese students' SMK levels and argumentation pedagogy and to provide insights into a possible research agenda focused on implementing argumentation in a heavily SMK-oriented context.

Keywords: *Argumentation; Subject Matter Knowledge*

Science education in China has put a great emphasis on Subject Matter Knowledge (SMK). Standard tests on SMK are the major approach to assessing students'

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achievement in science learning (Liu, Liang, & Liu, 2012). The emphasis on SMK in the Chinese science education system leads to the success of Chinese students' on internationally comparable exams. Such an orientation, however, also causes students to overemphasize the memorization of SMK and neglect other indispensable components of science, such as scientific attitudes and research skills (Gao, 2013). In order to address the problems in the education system, the central government in China launched an educational innovation known as New Curriculum Reform in 2003. Considerable progress has been made in the past 11 years in regard to theoretical understandings and administrative priorities, but little progress has been made in terms of classroom instruction and scientific literacy cultivation at the secondary level (Liu et al., 2012). Under the pressure of nationwide standardized exams, any educational innovations are unlikely to be accepted unless there is robust evidence suggesting their efficacy in promoting students' achievement on exams (Wu, 2010; Wu & Guo, 2012) or even be attempted unless teachers are assured such attempts will not negatively impact such achievement. Argumentation-integrated curriculum is one such innovation. Scientific argumentation is an essential scientific activity that leads to the development of an explanation based on empirical evidence. An initial foundation of SMK, in terms of the necessary background knowledge, is considered by many to be a vital component of argumentation and an enhanced SMK is one of the intended products of argumentation. The purpose of this sequential explanatory mixed methods study was to investigate the relationship between Chinese students' SMK levels and argumentation pedagogy and to provide insights into a possible research agenda focused on implementing argumentation in a heavily SMK-oriented context.

Background

Argumentation is defined as an interactive process of constructing explanations through an argumentative discourse in which individuals state and defend their claims, and meanwhile attend and respond to others' claims and defenses (Berland & Reiser, 2009). There has been an increasing emphasis on argumentation in science education at an international level (Berland & Hammer, 2012; Jimenez-Aleixandre & Erduran, 2007; Kuhn, 1991; Osborne, Erduran, & Simon, 2004; Osborne & Patterson, 2011; Simon, Erduran, & Osborne, 2006). The scientific enterprise has a controversial essence in that its research always yields equivocal findings or contested claims and science has been modifying itself in light of new evidence (Kuhn, 1991). In light of this, argumentation is considered an essential cognitive skill. Argumentation is required for inquiry-oriented science learning because it enables students to articulate their thoughts; justify their claims, and exposure to alternatives; defend against challenges and finally develop a better conceptual understanding themselves (Osborne et al., 2004).

Jimenez-Aleixandre and Erduran (2007) claimed a dual meaning of argumentation from both a social and an individual perspective. From the social perspective, argumentation refers to a persuasive interaction, such as disputes or debates, between people with opposing viewpoints toward an issue. From the individual perspective, argumentation refers to the reasoned utterance that reflects the process of individual thinking. Walton (1998) identified six possible argumentative dialogs, which were persuasion, inquiry, negotiation, information seeking, deliberation and eristic dialogs. Along with the six types of argumentative dialogs, Berland and Reiser (2009) suggested three functions of argumentation as articulation, sense making and persuasion.

Toulmin's model of argumentation identifies six components of an argument, including Claim (C), Data (D), Warrant (W), Backing (B), Rebuttal (R) and Qualifier (Q). The general pattern of making an argument is 'D, since W, on account of B, so C, unless R' (Toulmin, 1958). The components of data, warrants and backings are factual statements. Data are normally results from direct experiences, such as observations in science. Warrants are widely accepted facts, which in science are usually scientific theories or laws. Backings are the facts from which warrants are derived (Toulmin, 1958). Thus, SMK usually serves as justifications for an argument.

SMK is a critical component of argumentation. The construction and acceptance of SMK form a process during which argumentation plays a role in the rational development and resolution of questions and debates (Siegel, 1995). The selection of the optimum proposal against its alternatives depends on its validity in terms of its logical consistence and compatibility with evidence collected (Simon et al., 2006). A proposal should survive through the communication process of science communities before entering into science. Similar to knowledge construction in science, constructivism in science education is a belief that scientific knowledge should not be imparted to students but be constructed by students themselves based on their prior knowledge and daily experiences (Staver, 1998). Argumentation is a constructivist approach as it exposes the students to their own thoughts as well as their peers' ideas, through which students can extend their knowledge schema and rectify their misconceptions (Cross, Taasoobshirazi, Hendricks, & Hickey, 2008; Zohar & Nemet, 2002).

The relationship between argumentation and SMK raises a question to educators: are students with more sophisticated SMK better arguers? Some researchers ascribed students' poor performances in argumentation to a lack of related content knowledge (Sadler, 2004; Von Aufschnaiter, Erduran, Osborne, & Simon, 2008). High-quality argumentation is accompanied with sophisticated reasoning which requires a familiarity with the supporting evidence and its relationship with the claim (Osborne et al., 2004). Students are less likely to undertake high-quality argumentation with low knowledge level. Therefore, argumentation practices should be designed in relation to students' content-specific experiences and prior knowledge (Von Aufschnaiter et al., 2008).

There are empirical studies supporting such a positive relationship between SMK level and argumentation pedagogy. Zohar and Nemet (2002) claimed that engaging in argumentation could facilitate the transfer of SMK. On the other hand, greater mastery of content knowledge accounted for increasing quality and better performances in argumentation. Cross et al. (2008) conducted a case study to investigate the relationship between the quality of students' argumentation and their scientific understanding. The researchers closely observed three 10th grade African-American male students in a biology class. They found that the students who received relatively higher assessment gains in SMK tended to use better claim and warrant prompts and more rebuttals and qualifiers. Meanwhile, the students who were more knowledgeable about the subject were more comfortable and competent in argumentation. Sadler and Zeidler (2005) embedded their argumentation interventions in a controversial topic of gene-therapy and cloning dilemmas. Through comparing the participants' informal reasoning, the researchers found that there is no difference in students' patterns of informal reasoning (rationalistic, emotive and intuitive). The students with high genetics knowledge, however, were more likely to exhibit high-quality informal reasoning in terms of the coherence within a scenario and between scenarios, and the usage of rebuttals in a counter position.

There are researchers, however, who believe otherwise. They claim that the suggestion that a high level of SMK is required for successful engagement in scientific argumentation ignores the socially embedded nature of science. Scientific affairs demand thoughtful participations of all citizens rather than professional scientists (Zeidler & Keefer, 2003). If experts are believed to offer the best arguments, social-scientific decisions would be made from their perspective alone. The involvement of the public in scientific issues would be largely impeded. Kuhn (1991) claimed that the mastery of content knowledge did not necessarily determine the quality of reasoning and argumentation, as he said 'A large sophisticated knowledge base in a content domain does not determine the quality of thinking skills used in the domain' (Kuhn, 1991, p. 39). Experts do not always exhibit better forms of argumentative thinking in the domain of their expertise than they do in other fields. Furthermore, if the direct relation between SMK and argumentation exists, it is reasonable to deduct that argumentation skills can be transferred automatically from sophisticated SMK. In other words, argumentation can be a by-product of SMK learning. On the contrary, many researchers claimed that argumentation is an intellectual learning outcome that requires explicit instruction and specialized training (Berland & Reiser, 2009; Jimenez-Aleixandre & Erduran, 2007; Simon et al., 2006). There were researchers who found empirical evidence that suggested an insignificant relationship between quality of argumentation and understanding of related content knowledge (Means & Voss, 1996; Perkins, Farady, & Bushey, 1991).

Sadler and Donnelly (2006) proposed a two-threshold model (Figure 1) which was constructed from a neutral position regarding the relationship between argumentation quality and SMK level. According to this model, there are two thresholds that separate science laymen, science learners and science majors. The two thresholds represent 'necessary' and 'sufficient' amount of SMK in making effective and convincing argumentation, respectively (Cottrell, 2005). People should have necessary or minimum amount of content knowledge to meaningfully participate in an argumentative discourse and keep it going smoothly. People need sufficient content knowledge to make their arguments convincing. This model suggests a positive but nonlinear relationship between argumentation and SMK. It acknowledges the difference

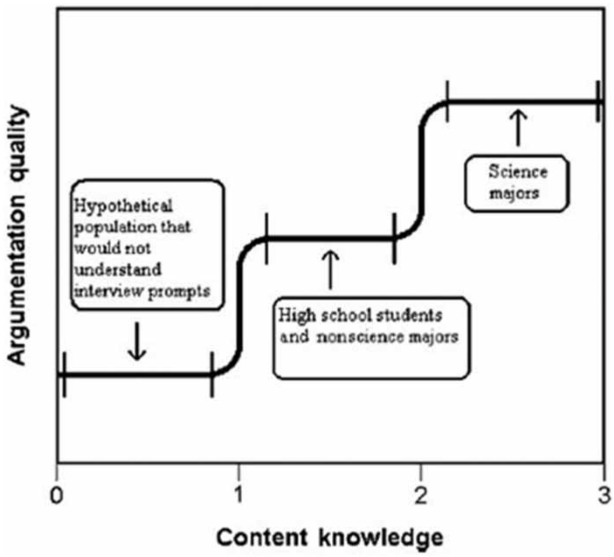

Figure 1. Two-threshold model (Sadler & Donnelly, 2006)

between experts and nonprofessionals in argumentation by putting the three groups of people in a hierarchical order. Within each group, there is no significant correlation. This model is supported by empirical evidence. Sadler and Donnelly (2006) interviewed the participants about three scenarios of gene therapy and cloning. They found that the college science majors outperformed the other groups in argumentation. There was no difference between nonscience majors and high school students.

The educational innovation in China known as New Curriculum Reform, launched by the central government, explicitly states that scientific literacy, including scientific attitudes and research skills, is a goal for secondary science education (Du, 2013; Liu et al., 2012). Despite the nationwide call for educational reform, science education remains heavily SMK oriented and classroom instruction at the secondary level still follows a traditional format of lecturing (Du, 2013; Gao, 2013). Many secondary science teachers express their lack of time, energy and most importantly a handy model that they can follow in implementing any substantial reforms in their classrooms (Gao, 2013). Science teachers would rather stick to a traditional way of teaching that has been proven to be effective in enhancing students' test scores. Scientific argumentation is believed to be an effective strategy in enhancing science learners' scientific literacy (Kuhn, 1991; Osborne et al., 2004; Von Aufschnaiter et al., 2008). Thus, we were seeking to foster argumentation pedagogy in secondary schools in China. The literature base, explored earlier, provided us with valuable understandings about the possible relationship between SMK and argumentation pedagogy in other contexts, yet questions remained. In addition, little is known about this relationship in Chinese schools. Thus, we sought to investigate the relationship between Chinese students' SMK levels and argumentation pedagogy and to provide insights into a possible research agenda focused on implementing argumentation in a heavily SMK-oriented context.

Research Questions

The overall efforts of this research were guided by the identification and monitoring of Chinese students' SMK achievement and how this achievement was affected by an argumentation intervention. The following questions guided the inquiry.

Quantitative Question

What is the relationship between secondary Chinese students' argumentation and SMK achievement?

(1) Does the practice of argumentation skills foster/hinder SMK achievement?
(2) Does sophisticated SMK determine high argumentation achievement?

Qualitative Question

What is the relationship between the secondary Chinese students' SMK level and their perceptions of argumentation pedagogy?

Mixed Methods Question

What is the relationship between secondary Chinese students' SMK levels and argumentation pedagogy?

Context

Participants

This study took place in a middle school in China over a six-week time period. The participants were 84 eighth graders and 2 experienced middle-level physics teachers, Mrs Tian and Mr Duan (pseudonyms were used). Mrs Tian's class, Class 17, received all the argumentation-integrated research interventions. This class included 42 students who were all Chinese. Mr Duan's class, Class 18, was set up as a reference class for the quantitative aspects of this research. As such, they did not receive any argumentation treatments.

Although developing students' scientific literacy, such as skills for scientific exploration, was one of the espoused educational goals for the science classes, the major goal was still achieving high scores in standardized tests. The teachers' bonuses and salaries were partially based on their students' performances in standardized tests. Mrs Tian was 36 at the time when this study was conducted. Like other young teachers in China, she was open to inquiry-oriented educational innovations but concerned most of the outcomes in terms of the efficacy of an innovation in strengthening students' SMK understandings. Therefore, although she agreed to implement the argumentation interventions, she insisted on maintaining much of the traditional format of lecturing as well. Mrs Tian did all the class instruction and grading. The researchers took charge of developing the argumentation interventions (described in the following). Mrs Tian met twice every week with the researchers to reflect on the efficacy of the research interventions that were implemented and to plan for the following week.

Research Interventions

At the time of this study, the students from both Classes 17 and 18 met three times a week for 40 minutes each class. The unit of instruction focused on light. The two classes used the same textbook for optics with the identical content knowledge required by the national standards of China. The entire unit comprised five topics. These included (1) light sources and shadow; (2) light reflection and the image from a mirror; (3) light refraction and total reflection; (4) lenses and the image from a convex lens and (5) lenses in everyday life. Class 17 received the research interventions including explicit instruction on argumentation, one argumentation question after each topic regarding a real-life problem and a role-play debate activity at the end of the unit.

Explicit instruction. Argumentation is an intellectual ability that requires explicit instruction (Osborne et al., 2004). Thus, the students learned about argumentation in terms of what it is and how an argument is constructed. The argumentation instruction featured Toulmin's (1958) model as the framework for students to formulate their arguments. The students used a revised version of the five-level analytic framework (Osborne et al., 2004) to self-assess their argumentation quality. We simplified this framework into a student-friendly version by combining data, warrant and backings together as justifications. The revised three-level rubric included (1) simple claims without justification; (2) claims with reliable justification and (3) claims made from multiple perspectives.

Argumentation prompts. The argumentation prompts designed for this intervention were related to and also extended from the content knowledge covered in class. The students were given one argumentation question after they learned a new topic. The questions were contextualized in real-life scenarios (Appendix 1). Answering these questions was a process of both practicing argumentation skills and implementing SMK in everyday lives. These open-ended questions required the students to provide their own ideas.

There was a role-play class debate at the end of the study period (Appendix 2). The scenario was that a university was doing a school-wide survey regarding a purchase of either reflective or refractive telescopes for astronomical observation. There were four groups of people, school managers, professors, students and mechanics, who had different considerations. Students were divided into four groups according to their SMK level and argumentation skills so that all the teams matched up in content knowledge and talkativeness. Each group was assigned a role, and then they debated over which telescope should be purchased from their unique perspective. Finally, the researchers summarized this debate activity with two key points: (1) there is no right answer in this story. The 'optimum decision' is determined by people's standpoint, which is usually biased; (2) besides the two telescopes provided, there is another one called catadioptric telescopes that adopt the advantages of both reflectors and refractors. An either–or selection sometimes can have a third option. This summary was to point out to students that they should think creatively and avoid trapping their thoughts within a certain paradigm.

Method

In order to address the research questions noted earlier, a sequential explanatory mixed methods design (Creswell, 2003) was utilized. The two methods were integrated during the interpretation phase (Figure 2).

Quantitative Data Collection and Analysis. The quantitative data included students' SMK levels and argumentation scores.

SMK. Students' SMK level was gauged by standard tests of optics for the eighth grade. In order to avoid biased data, we did not design a specific test that aligned with the research interventions. Instead, we used the tests that Mrs Tian normally used for SMK assessment. These tests were constructed by the board of education in Haidian District of Beijing. The tests contained questions in a traditional form of multiple choices, short answers, graphing and calculations, which were targeting exactly on the content knowledge required by the national standards. All the middle schools in Haidian District, including the one where this research project took place, were using the same tests in order to make horizontal comparisons among schools. These tests matched the instructional objectives in Classes 17 and 18, or precisely speaking, the instructional objectives in the two classes were set up to prepare the students for the standard tests. As stated before, secondary science education in China is test driven;, thus, instructional objectives are designed to prepare students to attain high scores on local and national tests (Du, 2013; Gao, 2013; Wu, 2010). Both classes in this study took the identical pre- and posttests, which were graded by Mrs Tian and Mr Duan, respectively, using the same rubric. In this manner, students test scores could objectively reflect their SMK understanding.

The students' scores in both pre- and posttests were collected in a scale of 0–100 points. A paired *T*-test was conducted on the pre- and posttest scores of Class 17

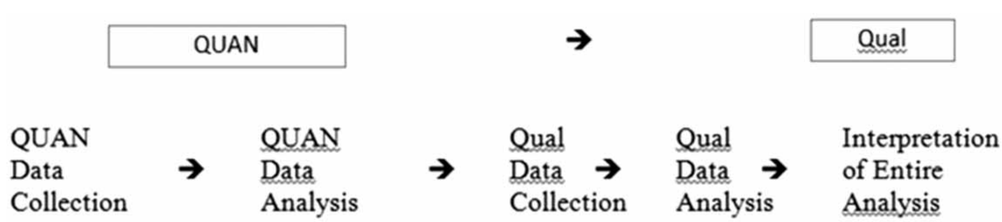

Figure 2. Sequential exploratory design (Creswell, 2003, p. 213)

and Class 18 separately to understand whether the students' SMK development was significant. Then we employed an independent *T*-test to compare the differences in test scores between Class 17 and Class 18 to gauge the efficacy of the research interventions. In order to investigate the relationship between SMK and argumentation quality, we ran a Pearson correlation between the test scores and written argument points of the students in Class17. In this study, students' SMK level was measured by their achievement in standardized tests. The students in Class 17 were classified into three groups according to their average score of the two tests, which were High (H, >80), Medium (M, 70–80) and Low (L, <70). Written arguments from Class 17 were collected for quality analysis. The method is discussed in the next section.

Argumentation. Argumentation data from Class 17 included the students' written and verbal arguments. The students' written arguments came from their answers to the argumentation questions. One argumentation question was distributed to students every week as homework. The students had at least two days to work on each question. In an effort to avoid increasing the already heavy homework load of the students, Mrs Tian did not assign points on the argumentation questions. This assignment was not mandatory. Mrs Tian only had 40 minutes in each class and she had a tight schedule to follow. Therefore, she could not cover all the responses from the students. Instead, Mrs Tian and the researchers worked together selecting the most representative responses for class discussion. Such representative responses either matched Mrs Tian's instructional goal for a certain class or could potentially raise argumentation among students. The class discourses were video recorded as the source of students' verbal arguments and transcribed later.

The analysis started with the identification of argumentation. Argumentation overlaps with explanation to some extent. An explanation is a causal account established based on evidence and logical reasoning, whereas an argument is a statement with certain amount of tentativeness that functions to negotiate ideas (Osborne & Patterson, 2011). Berland and Reiser (2009) stated that 'explanations of scientific phenomena can provide a product around which the argumentation can occur. Argumentation creates a context in which robust explanations are valued' (p. 28). This viewpoint takes argumentation as the process and explanation as the product of a discourse. An explanation is the winning argument that best fits evidence and awaits further challenge. This definition of argumentation fails to reflect all the types of argumentative discourses (Walton, 1998) and all the functions of argumentation (Berland & Reiser, 2009). We believed that the line is vague between an explanation and a general concept of argumentation. An explanation is a product of argumentation. Meanwhile, it can also serve as the elaboration of a claim or the justification of an argument.

In this study, we did not espouse the position that argumentation is equivalent to explanation. However, our emphasis was not on differentiating argumentation from explanation. For practical convenience, we defined argumentation as a spontaneous statement with a clear position in the attempt to contribute to a discussion. According to this definition, students' responses simply as the answer to the teacher's question while being called up were not counted as arguments. Sometimes the students made unexpected or even eccentric statements just for the sake of drawing the attention of others, or challenged the teacher for amusement. These words were not counted as arguments either. Considering the fact that physics in middle schools in China relied on math already, the graphs and math deductions that students used to support a conclusion were considered as parts of an argument.

In this study, the participants' argumentation was assessed from the following three perspectives: (1) students' engagement in argumentation; (2) the structure of an argument and (3) the content of an argument. They are discussed in detail in the following section. Their relation with the data sources are shown in Table 1.

Written arguments. Students' written arguments were first assessed on the structure based on the rubric shown in Table 2, which was adjusted from the scoring schema constructed by Osborne et al. (2004) as well as Sadler and Donnelly (2006). Then we adopted the idea of epistemic levels to assess the content of the written arguments (Kelly & Chen, 1999; Kelly & Takao, 2002). Kelly and Takao (2002) designed a six-level rubric to assess arguments in oceanology. This rubric could not be directly used because it was content specific. However, the idea behind is inspiring, which is a hierarchy in conceptual understanding from Level 1 'propositions making explicit reference to data charts, representations, locations, and age of islands, or locating the geographical area of study' to Level 6 'general propositions describing geological processes and referencing definitions, subject-matter experts, and textbooks, and the knowledge represented may not necessarily refer to data that is specific to the area of study'. The hierarchy represented a continuum from concrete evidence to abstract inferences and then to general laws/theories regarding a topic. We adapted this idea into our context. We focused on the quality of justifications, that is, what constituted data, warrants and backings of an argument. Consequently, we cared about whether the students were aware and capable to interpret data with the physics concepts required by standards rather than how exactly they interpreted the data. Thus, we combined Level 3 'relative geographic relations' and Level 4 'geographic model' in Kelly and Takao's model into one level of relating data to key concepts in optics. We valued the capability of coordinating various theories in a network of knowledge and assigned it as the highest level (Table 3). The students were expected to retrieve not only the SMK learned in class, but also the knowledge learned from other resources as the alternative to the authentic knowledge. They needed to reconcile different types of knowledge to support their claim. Afterwards, a statistical analysis was

Table 1. Argumentation assessment and its corresponding data source

Argumentation	Data source	Description
Engagement	Verbal arguments	Frequency of arguing, contribution to pushing forward a discussion (Table 4)
Structure	Written arguments	Components of argumentation (Table 2)
Content	Verbal arguments	Quality of justifications (Table 4)
	Written arguments	Epistemic level of justification (Table 3)

Table 2. Rubric for assessing argumentation structure, adapted from Osborne et al. (2004) and Berland and Reiser (2009)

Criterion	Score	Description
Claim and evidence	2	Arguments with clear claims which are based on reliable premises and evidence
	1	Arguments with clear claims and identifiable evidence, but the evidence or the premises are fallible
	0	Arguments with only simple claims or counterclaims
Justification	4	Arguments with identifiable warrants, and arguments are coherent and logically consistent
	2	Arguments with identifiable warrants. They fail to connect evidence to claims because of logical inconsistence
	0	Arguments with only claims and evidence, but no warrants are provided
Multiple perspectives	6	Alternative perspectives are considered. Primary and secondary explanations are thoroughly compared and analyzed in light of evidence
	3	Alternative explanations are considered but not analyzed in comparison to primary explanations, or evidence is not provided
	0	Arguments without consideration of alternative explanations

Table 3. Rubric for assessing argumentation content, adapted from the six-level epistemic framework (Kelly & Takao, 2002)

Level	Types of justification (data, warrants and backings)
4	Reconciled knowledge network (knowledge of other physics topics, from other disciplines)
3	Key knowledge in optics
2	Inferences from data
1	Description of data, charts, etc.
0	Incorrect content knowledge and no justification

conducted to investigate the correlation between SMK scores and argumentation structure scores, and between SNK scores and argumentation content levels, respectively.

Verbal arguments. The students' verbal arguments were sought to help us understand the pattern of argumentative dynamics of the students with different SMK levels. Each physics class in Class 17 was video and audio recorded. One camera was set up at the back of the class to capture the class dynamic. An audio recorder was also used to mainly capture the statements from the students, especially when their voice was low. All the videos and audios were transcribed. We first identified argumentation from the transcripts of classroom discourses. After that, we used the scheme shown in Table 4 to code each argument. For each argument, we determined the SMK level of the arguers first, then the argumentation type as either between a student and a teacher or between students, and the goal of the argument in terms

Table 4. Coding scheme of students' verbal arguments

Elements	Coding scheme
Arguer	Students with High SMK (H) (> 80)
	Students with Medium SMK (M) (70–80)
	Students with Low SMK (L) (<70)
Argumentation type	Between student and teacher (ST)
	Between students (SS)
Goal of argumentation	Articulating (deliberating to predict outcome) (A)
	Sense making (inquiry and information seeking) (S)
	Persuading (persuasion) (P) (Berland & Reiser, 2009)
Quality of justification	Without justification (W0)
	Supported by correct key SMK from the textbook (W1)
	SMK cited but incorrect (W2)
	Supported by knowledge from other sources, such as online information, personal experiences and experimental data (W3)
Contribution of new perspective(s)	Yes (Y)
	No (N)

of articulating, sense making or persuading, followed by the quality of justification, and finally whether the argument contributed a new perspective that can push forward the discussion.

Qualitative Data Collection and Analysis. We conducted one focus group interview for the data collection procedure after the intervention was complete. Nine students from Class 17 with different SMK capabilities voluntarily participated in a focus group. The focus group interview was audio recorded and transcribed later. The foci of the interview included the students' feedback to their regular physics instruction and to the research interventions. The researcher who conducted the interviews was a Chinese male and former physics teacher with training in conducting interviews. Sample interview questions include the following:

- What does physics mean to you? What do you think is the best way to learn physics?
- Which part(s) of the argumentation activities do you like? Dislike?
- To what extent do you feel the argumentation activities are helpful to your exams? To your understanding of physics content knowledge?
- Did you like the argumentation questions as well as the final debate activity?
- Have you ever thought about how you can implement what you have learned in physics in real lives?
- How related are the argumentation questions to the physics content knowledge required by the standards?
- Do you feel that the argumentation activities are parallel to what you are actually doing in class?

We analyzed the qualitative database using traditional qualitative procedures for coding and developing themes (Creswell & Clark, 2007). One member of our research team transcribed the audiotapes from Chinese to English. We used an in vivo coding technique to represent the students' words as closely as possible. For instance, we coded students' SMK categories as 'L' (low SMK), 'M' (medium SMK) and 'H' (high SMK) and their attitudes and/or comments toward different instructional approaches ('Re' for regular instructional dynamics and 'Ar' for argumentation activities) as '+' (positive) , '|' (neutral) and '−' (negative). We refined the codes throughout the design process as new ideas emerged, and similar codes were grouped together into broader themes (e.g. high-SMK students' overemphasis on the accuracy of conclusions and their doubt on their qualification of giving high-quality arguments, medium-SMK students' enthusiasm to experiments and their appreciation of empirical evidence and low-SMK students' hatred of extra working loads and their physical but not mental engagement in argumentation). Each theme was discussed and clarified until a final set of major themes emerged that best represented the perspectives of the students.

Findings

Quantitative Results

What is the Relationship Between Secondary Chinese Students' Argumentation and SMK Achievement? **Test scores.** The average scores on pre- and posttests for Class 17 were 64.66 and 70.08, respectively, with an increase of 6.14. The reference class, Class 18, had average scores of 73.26 and 78.24, respectively, with an increase of 4.98. A paired *T*-test was conducted in both cases to compare the difference between the pre- and posttests. The results indicated that the increase in the test score in both classes was significant (Class 17, $\alpha = 0.002$ and Class 18, $\alpha = 0.009$). Then we conducted an independent *T*-test to compare the difference between the increases in the test score in the two classes. The difference was not significant ($\alpha = 0.375$). These data showed that both classes made progress in content knowledge understanding after six weeks of learning. The improvement in Class 17, however, was not significantly more than that of Class 18. Therefore, we could not attribute the improvement of SMK to the interventions that Class 17 received. In other words, there was no evidence in this study that supported the notion that argumentation practices foster/hinder SMK understanding, which resonated with the studies that suggested no direct relationship between argumentation and SMK (Kuhn, 1991; Means & Voss, 1996; Perkins et al., 1991).

Written arguments. We assessed the structure of the students' written arguments from Class 17, and then ran a correlation analysis between the structure points and the test scores. The argumentation questions were not mandatory. The students could select the questions that interested them. Thus, we could only collect responses from a portion of the students for each question (Q1, 33 responses; Q2, 33 responses; Q3, 16 responses; Q4, 16 responses; Q5, 24 responses and Q6, 26 responses). Argumentation questions 1, 2, 5 and 6 were selected for the correlation analysis with test scores because they were responded to the most by the students. Furthermore, in an effort to gauge students' argumentation skills at a specific moment, the four questions

Table 5. Correlations between test scores and argumentation structure points

	Q1	Q2	Q5	Q6
Pretest	0.356*	0.429*		
Posttest			0.165	0.313

*Correlation is significant at the 0.05 level (two tailed).

were given out close to the respective pre- and posttest for that subject. Students' answers to Q1, Q2, Q5 and Q6 were first assessed on the structure (Table 2). The result of the correlation analysis (Table 5) showed that the scores of the argumentation structure were not significantly or highly correlated with the test scores, which indicated that students' SMK level did not significantly influence the usage of the argumentation model and the organization of argumentation components.

Then we assessed students' written arguments on the content (Table 3). We took out Q2 and Q5 because the SMK required to answer the two questions has already been provided in the description of the two questions (Appendix 1). The students' answers to the two questions showed that they cited the same content knowledge to back up their claims. Thus, there was no variation among the scores in argumentation content that the students received for the two questions. We ran a correlation analysis between the test scores and the argumentation content scores of Q1 and Q6. The result (Table 6) showed that the argumentation content levels were significantly correlated with the test scores, but the correlation coefficients were low. This result suggested that SMK levels determined the argumentation content to some extent, but not significantly. The students with sophisticated SMK performed slightly better than their weak-SMK peers in the ability to synthesize outer information and coordinating inner knowledge schema. They were more capable to retrieve not only contingent knowledge but also general knowledge related information.

Verbal arguments. All the data of verbal arguments were coded in reference to Table 4 and are summarized in Table 7.

Argumentation type. In total, 135 verbal arguments, 87 from regular classes and 48 from the role-play debate, were identified. The medium-SMK students argued most in normal class dynamics (56.32%). They were most active in class discussion. Scientific arguments occurring between these students and their teachers outnumbered those occurring with their peers. In contrast, the students with different SMK levels contributed relatively equally to the class discussion during the debate (H: 39.58%, M: 37.50% and L: 22.92%). The majority of the arguments happened among students. The students paid more attention to and responded more to their peers' ideas in the class debate. Overall, the high-SMK students argued a lot more. They seemed to be more willing to argue in a disputable activity over an open-ended question. This evidence supported that a controversial context is effective in engaging students in argumentation (Johnson & Johnson, 2009). Another finding was that the low-SMK students were the quietest in argumentation despite the type

Table 6. Correlations between test scores and argumentation structure points

	Q1	Q6
Pretest	0.559**	
Posttest		0.540*

**Correlation is significant at the 0.01 level (two tailed).

*Correlation is significant at the 0.05 level (two tailed).

Table 7. Data of verbal arguments for High (H)-, Medium (M)- and Low (L)-SMK students

		H	M	L
Argumentation type (regular class dynamics)	SS	3	6	2
	ST	22	43	11
	Total	25	49	13
	Percentage	28.74	56.32	14.94
Argumentation type (role-play)	SS	17	14	10
	ST	2	4	1
	Total	19	18	11
	Percentage	39.58	37.50	22.92
Goal of argumentation	Articulating	40.90%	32.84%	41.67%
	Sense making	20.45%	26.87%	20.83%
	Persuading	38.65%	40.29%	37.50%
Quality of justification	Without justification (W0)	27.27%	55.22%	50.00%
	Supported by correct key SMK from the textbook (W1)	36.36%	11.94%	8.33%
	SMK cited but incorrect (W2)	4.55%	11.94%	4.17%
	Supported by knowledge from other sources (online information, personal experiences and experimental data) (W3)	31.82%	20.90%	37.50%
Contribution of new perspective(s)		16.67%	75.00%	8.33%

or the environment of discourses. Insufficient content knowledge seemed to impede their participation in argumentation.

Goal of argumentation. The high-SMK students used argumentation primarily to articulate (40.90%). Their argumentation served as an implementation of their content knowledge. Interestingly, the situation was the same for the low-SMK students who 'Articulating' took up the largest portion (41.67%). Most of the arguments from the medium-SMK students functioned as persuasions (40.29%). It seemed that medium-SMK students were most aggressive arguers because they were most keen to convincing others to accept their ideas. One similarity among the three groups of students was that 'sense making' took up only a small portion. The students did not perceive argumentation as an approach to inquiry learning despite their SMK level. Instead, they valued the interactive nature of argumentation.

Quality of justifications. Nearly three quarters of the arguments from the high-SMK students were justified. Thus, they achieved the highest level of argumentation in terms of the usage of justification. High-SMK students cited correct content knowledge from the textbook, which comprised the largest portion of their justification. This fact corresponded to their mastery of the content knowledge. Medium- and Low-SMK students shared two similarities. One was that a large portion of their arguments was simple claims without any justifications, which undermined the strength of their arguments. The other was that the largest portion of their justifications was composed of the knowledge beyond the textbook. This phenomenon was probably due to the insufficient content knowledge of the two groups of students, which made them resort to other sources of information. In this sense, Medium- and Low-SMK students valued a variety of data sources, such as their personal experiences, more than the High-SMK students.

Contribution of new perspective(s). Among the total 135 verbal arguments, 24 (17.78%) contained a creative idea or a new perspective that pushed forward class discussion. Medium-SMK students contributed most of the new perspectives (75.00%). High-SMK students ranked the second. This was another piece of evidence supporting that the Medium-SMK students were most engaged in argumentation practices.

Qualitative Results

What are the Relationship Between the Secondary Chinese Students' SMK Level and their Perceptions of Argumentation Pedagogy? Nine students from Class 17 voluntarily participated in the focus group interview. This group included four High-SMK, three Medium-SMK and two Low-SMK students. The participants shared their opinions toward the research interventions. We sorted out some representative comments from students with different SMK levels to illustrate the discussion of findings.

High-SMK Students: (H1) *They* (*the argumentation questions,* Ar) *overlapped with what we learned in class. They were related to my life which helped me notice something I had not paid attention before* (LP-ka) *and think about something that I had taken for granted* (LP-tp) (+).

(H2) *I never thought about knowledge application before. They (the argumentation prompts) provided me a chance to do that* (LP-ka) (+).

(H3) *I don't think we are qualified enough for inquiry* (Ar). *We don't have sufficient knowledge* (SMK) *or skills. So not ready yet* (−).

(H4) *I like debating, but a debate should go somewhere, or I should learn something from it* (SMK). *Otherwise it's just a waste of time* (|).

Medium-SMK Students: (M1) *I felt that the knowledge* (SMK) *was less abstract than it used to be when I had a chance to use it* (LP-ka) (+).

(M2) *Daily life problems* (Ar) *(embedded in the argumentation questions) were much more complex than questions in tests* (Re) (|).

(M3) *I like experiments in physics* (LP-ex) ... *We barely have labs, I wish we could have more* (Re) ... *I like to have some opportunities for investigation. I don't like being told everything by teachers* (LP-ex) (+).

(M4) *You (Wang) should've not told us the steps for the experiment, such as measuring the speed of light. Let us design the experiment first* (LP-ex). *If we are stuck, then help us* (+).

Low-SMK Students: (L1) *They (the argumentation prompts) made physics not that dull* (+).

(L2) *They (the argumentation prompts) opened up my mind* (LP-tp), *but they didn't quite help with the tests* (SMK)(−).

(L3) *They (the argumentation questions) are fun* (Ar). *I like the questions without one right answer* (+).

(L4) *They (the argumentation questions) are interesting* (+). *However, they were a burden to me. I was exhausted trying to finish homework every day* (Re). *I did not want to spend any time on extra work* (SMK) ... (−).

(L5) *I don't understand why they argued so fiercely in class. You (Wang) already told them that there was no one right answer and it was not required by the standard* (SMK). *It was just agree and disagree* (Ar) (|).

Overall, these students from the various SMK levels perceived the argumentation interventions positively and noted that argumentation made their physics learning more interesting. Although it could not be inferred to what extent the research interventions benefited the students, they were at least engaged. It could be seen from H1, H2, M1 and L2 that the interventions succeeded in facilitating students' learning process (LP) by providing the opportunities for either thinking practice (LP-tp) or knowledge application (LP-ka). We also noticed that the students' different concerns about argumentation reflected their epistemologies. The quotes from High-SMK students indicated that they cared more about the mastery of SMK, although they enjoyed the process of argumentation. According to H3, inquiry referred to the new approach of instruction represented by argumentation. High-SMK students perceived SMK as the prerequisite for meaningful argumentation. Thus, they thought that students at their level were not qualified enough to participate in argumentation. In other words, High-SMK students accepted the importance of argumentation but perceived it as not applicable at the secondary level. As shown in H4, High-SMK students thought that argumentation was effective only if it could lead them to the right answer. Together, they seemed to give priority to learning outcomes rather than learning processes. In contrast, Medium-SMK students focused more on the learning process. They exhibited the epistemology that science is an approach to investigation rather than simply a collection of facts. As shown in M3 and M4, Medium-SMK students were most keen on student-sponsored exploration (LP-ex). They perceived argumentation as an opportunity to fulfill their need of taking control of their own learning. Compared to their High-SMK peers, Medium-SMK students were less likely to look to authority for answers. They seemed to have an understanding of the empirical nature of science. Thus, Medium-SMK students were most likely to be spontaneous learners. As for Low-SMK students, we could see from L1 and L3 that Low-SMK students enjoyed argumentation partly because it was new to them. There was little evidence suggesting that Low-SMK students perceive argumentation as the learning process that could help them promote their conceptual understandings. Instead, they perceived argumentation as a new type of instructional approach. According to L3 and L5, it could also be inferred that argumentation was interesting to Low-SMK students because it was less stressful than the regular instructional tasks. Low-SMK students probably did not see the connection between argumentation and their SMK learning. L2 and L4 indicated that Low-SMK students' limited SMK impeded them from participating meaningfully in argumentation. Generally, Medium-SMK students seemed to value argumentation most and benefit most from the argumentation interventions.

Mixed Methods Discussion

What is the Relationship between Secondary Chinese Students' SMK Levels and Argumentation Pedagogy? This study was aimed at understanding the relationship between argumentation and SMK at the secondary level in China. There was no statistical evidence suggesting a linear relationship between them. On one hand, no evidence supported that the argumentation-integrated research interventions significantly promoted the students' SMK achievements. However, our data suggested that the argumentation practice did help students with their argumentation skills without harming their SMK understanding. The practice of argumentation is a long-term process. Thus, it is less likely for students to master argumentation and apply it proficiently in their learning within six weeks. The increase in arguments among students in the class debate as well as the positive feedback from the students suggested that the argumentation activities were effective in engaging students in science learning. Argumentation activities built a platform on which the students had more flexibility to take control of their own learning. Engagement is critical in the shift of students' role from passive receivers to active learners. Meanwhile, these activities brought a chance to the teacher to gauge her students' thoughts.

There were no findings that suggested that the students' SMK level significantly or largely affected the structure or content of their arguments. In other words, the students with more SMK were not necessarily better arguers. Thus, the answer to the question of whether sophisticated SMK determined high argumentation achievement was complex that could not be boiled down to yes or no. However, we could tell from the data that Medium-SMK students were most engaged, followed by High-SMK students and then Low-SMK students. Plus, the data of verbal arguments showed that High-SMK students were most aware of using justifications to back up their claims. Therefore, we could summarize the argumentation patterns of the three groups of students.

For High-SMK students, the accuracy of content knowledge was of their priority, which they thought should be the destination of argumentation and the authentic source of evidence. During this research, High-SMK students were most eager to know the correct answer to the argumentation questions given by the researchers or Mrs Tian. They were uncomfortable with the argumentation yielding equivocal conclusions. To them, sufficient SMK is the prerequisite for meaningful argumentation. Argumentation was a process to strengthen their existing knowledge through applying it in different scenarios, rather than a knowledge construction process through which they could expand their knowledge schema. Thus, it could be inferred that High-SMK students were looking for the truth held by the authority during the argumentation activities, instead of the best explanation among the ideas of themselves and their peers.

Compared to High-SMK students, Medium-SMK students were more aware of the function of argumentation as an approach to knowledge construction. They did not want the involvement of authority as much as High-SMK students did. During this research, most of the challenge came from the Medium-SMK students. This fact indicated that Medium-SMK students did not perceive the researcher and Mrs Tian as truth revealers, but as arguers like themselves. They enjoyed the process and paid less attention to the outcome of argumentation. They cited knowledge from other resources most, including empirical knowledge. In this sense, Medium-SMK students did best in connecting what they learned in class to what they encountered in their lives. Meanwhile, Medium-SMK students cited inaccurate knowledge most, which indicated that they were less capable than their High-SMK peers to coordinate a large amount of information or to determine the reliability of a data source.

Low-SMK students were least capable of participating in argumentation meaningfully. They were less skillful in argumentation than the other two groups of students from all perspectives. This result was partly due to that their SMK level did not reach the 'sufficient' threshold (Sadler & Donnelly, 2006). It probably also had something to do with their identity of low achievement students. The test scores were released to the entire class in China (Gao, 2013). Low-SMK students' bottom rank in tests might shake their confidence of sharing their own ideas in normal class settings. Argumentation was a new classroom activity that was more interesting than lecturing. Meanwhile, argumentation put less emphasis on memorizing content knowledge. Thus, Low-SMK students took argumentation as an opportunity to interact with their peers, have fun and express themselves in class. During the research, Low-SMK students were either the quietest or the most distractive.

Through looking across the three groups of students, the argumentation pattern of Medium-SMK was closest to that of scientists. Medium-SMK students seemed to have the best understanding of the inquiry process and the constructivist epistemology in science. Both of the understandings are critical to scientific argumentation (Staver, 1998). High-SMK students exhibited the best mastery of required SMK. However, their overemphasis on the learning output impeded them from benefiting from the argumentation process. Meanwhile, their identity of high-achievement students made them pay little attention to their peers' ideas but resort to the authority for answers. In this study, High-SMK students argued as much as Medium-SMK students only in the class debate. High-SMK students did not see the necessity of argumentation in normal class settings because they were already familiar with the target knowledge or they believed that the teacher held the truth. Thus, they did not perceive argumentation as an approach to expanding their knowledge. Argumentation, as a part of the knowledge construction process, happens when there is uncertainty (Walton, 1998). In this sense, Medium-SMK students have the greatest potential to become good arguers.

Conclusion

China is experiencing a reform in curriculum and instruction, but the assessment still follows the traditional way of standard tests evaluating students' familiarity with factual knowledge taught in class rather than conceptual understanding (Wu & Guo, 2012). The questions in standard tests are mainly plug-in calculations embedded in abstract science models (Gao, 2013). Teachers would demonstrate the solution to a question over and over again before placing it in a test. Thus, students with high scores in tests probably are more diligent or with a better memory but not necessarily more knowledgeable in physics. Similarly, good science students in China may be good test takers, but not necessarily ones with better scientific literacy. Considering this fact, our finding is reasonable that Medium-SMK students had greater potential than High-SMK students in argumentation. The overemphasis on the learning outcome of students inevitably leads to an overlook of students' learning process. It is time for science educators in China, or generally in a SMK-oriented context, to think about this question: are students trained to be science learners who know scientific facts or science pioneers who make explorations?

Practically, in order to disseminate argumentation in China, successful empirical examples are needed that clearly show how students benefit from the practice of argumentation in SMK achievement. Science education in China is theory focused, national exam oriented and homework supplemented (Gao, 2013). The assessment relies heavily on SMK understandings. Science teachers are under great pressure from the high-stake tests. Any educational innovation should be proven beneficial to, or at least not harmful to, the test-oriented educational goal. Otherwise, teachers would select a traditional conservative approach rather than risk their students and their own career by using the argumentation-integrated method. This study yielded evidence suggesting that the argumentation interventions did no harm to students' SMK learning as required by the national standards of China. Meanwhile, the interventions were effective in enhancing students' engagement in physics classes. In this sense, this study was a successful example to convince science teachers in China to incorporate argumentation in their classes.

From the students' perspective, this study described different argumentation patterns of students with different SMK levels. Argumentation quality was assessed from engagement in argumentation, argumentation structure and argumentation content. Low-SMK students were less capable than the other two groups in all the three categories. There was no robust evidence showing the difference between High-SMK and Medium-SMK students in argumentation structure or content. However, Medium-SMK students defeated their High-SMK peers in engaging in argumentation. The significance of engagement in argumentation is emphasized by several scholars (Berland & Hammer, 2012; Cross et al., 2008; Osborne et al., 2004). Thus, we think that Medium-SMK students in China have the greatest potential to become good arguers or benefit from argumentation practices.

Accordingly, we suggested a revision on the secondary level of Sadler and Donnelly's model in the context of China (Figure 3). We kept in mind that our study was based on a sample of middle school students in China. Although middle school students and high school ones are in different grade levels, they are both secondary students who have just started embarking upon their science journey. Furthermore, the middle school students in China are similar to high school students in the US content wise after comparing the national standards for eighth grade physics in China with the national standards for high school students in the USA. Thus, it is safe to say that our sample corresponds to the group of 'high school students and non-science majors' in Sadler and Donnelly's model. This study provided more information about the middle level, that is, the line between the two thresholds, in Sadler and Donnelly's model. We zoomed in this line and suggested that it was not straight. There were differences among students with different SMK levels. The line was not continual because it was constructed based on the difference among three separate groups of students. There was no robust quantitative data suggesting any linear relationship between the students' SMK and argumentation. The two new thresholds were not associated with any specific skills or knowledge, but were used to separate groups of students with the potential of becoming good arguers. Our proposal of the revised model is just a start of investigating the effect of secondary students' content knowledge on their argumentation quality and the reverse process. A long-term project in the future regarding argumentation and SMK, in addition to

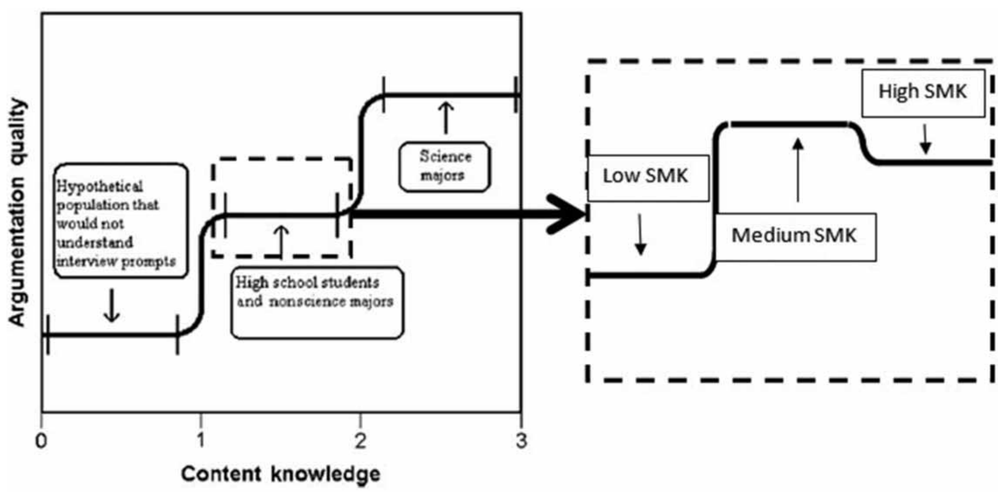

Figure 3. Suggested revision on Sadler and Donnelly's model at the secondary level in the context of China

our existing understanding, will depict a more clear and detailed picture about the direct relationship between argumentation skills and SMK levels.

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Appendix 1. Argumentation questions

Argumentation 1

Sundials are timing instrument used in ancient China (Graph 1). A sundial is composed of a sundial needle and a sundial surface. The sundial surface is parallel to the equator, and it has a certain angle to the ground. Please try to explain how a sundial works, give your reason and illustrate how to set up the inclinational angle for a sundial.

Graph 1. A picture of a sundial

Argumentation 2

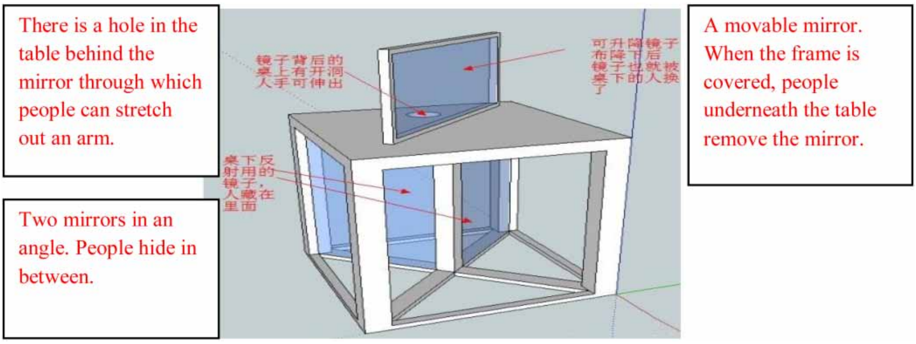
The speed of light is extremely fast that it can travel a long distance within a short time. Therefore, we cannot measure the speed of light in a traditional way of $s/t = v$. This task can be done with daily-used materials at hand. Take out the plate from a microwave oven. Place a big flat piece of chocolate (probably 20 cm × 10 cm, or even wider) in it. Keep the length of the chocolate parallel to the door of the microwave. Make sure that the chocolate cannot spin inside. Heat it at low power levels for 2–3 minutes. Take out the chocolate. (1) Observe what happens on the chocolate. (2) The peak and valley of a wave are where the energy is maximum. Based on the melting pattern on the chocolate and the frequency labeled on the microwave oven f, calculate the speed of light based on the formula $v = f\lambda$. (Microwave shares the same properties as visible lights. It is one type of electromagnetic wave where λ is the wavelength.)

Argumentation 3

Modern buildings covered with glass walls decorate cities with modernization and magnificence. However, glass walls also bring some hazards. They could reflect sunshine to the ground, and the stunningly bright spots might cause temporary blindness. The potential hazards threaten the drivers and passengers, which is referred to as light pollution. Please work out a solution to reduce the effect of optical pollutions, and meanwhile try to not wreck the beauty of a city. Provide your reasons.

Argumentation 4

The magician Louis Liu performed a magic trick at the 2012 spring festival gala, ‘world in the mirror’. The secret of this magic was later revealed online. The magic props are shown in Graph 2. Please try to explain why it looks empty underneath the table when the mirrors are placed in that way. Provide your reason.



Graph 2. The magic props for ‘world in the mirror’

Argumentation 5

According to the textbook, virtual mirage is a result of light refraction where light is bent after traveling through air of different densities. Graph 3 is a picture of virtual mirage captured above sea. We can see that it is an upright island floating in the air. Graph 4 is a picture of virtual mirage captured in desert. It is an upside-down image of the house below the horizon, which looks like the reflection of the house in sand. (1) Please try to explain these two phenomena with ray diagrams. (2) The textbook says that the virtual mirage above sea is always upright. Someone took a picture of a virtual mirage, which was an upside-down image of a boat (Graph 5). Could this picture be taken as counter evidence to the claim made in the textbook? If yes, justify your answer. If no, please explain this phenomenon.

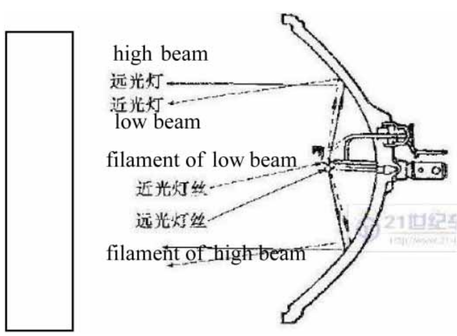
Graph 3. Upright mirage above sea

Graph 4. Upside-down mirage in desert

Graph 5. Upside-down mirage above sea

Argumentation 6

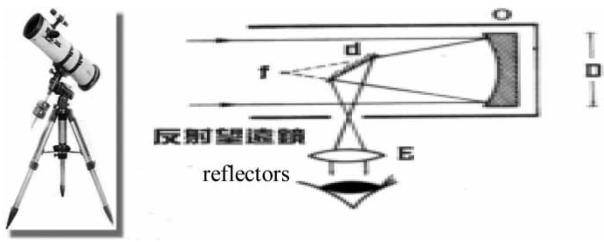
The headlights of a vehicle have both dipped/low and full beam. Dipped/low beam helps a driver see clearly the road condition in front of a vehicle. It is used during normal driving at night or in adverse weather conditions. Full beam enables a driver to have a clear view over a long distance. It is used when the road ahead is clear and no vehicle is driving toward you in an opposite direction. Graph 6 shows the structure of headlights. The diverging light is reflected by a concave mirror first and then it travels through a lens (shown as a frame). The function of this lens is to (1) enlarge the zone of illumination and 2) concentrate light beam in front of a vehicle so that it can travel forward further. Based on the information, should this lens be a convex or concave lens? Justify your answer.



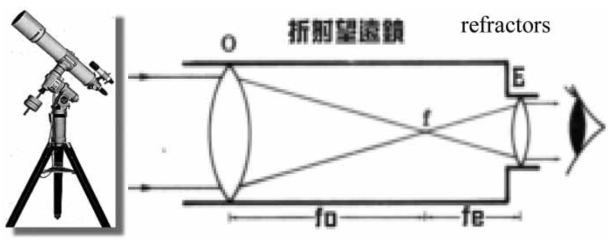
Graph 6. The structure of headlights

Appendix 2. Role-play debate

A university plans to buy some astronomical telescopes for celestial observation. The final decision has been narrowed down to two options: reflectors (Graph 7) and refractors (Graph 8). After a school-wide survey, four different opinions are identified: (A) the school managers care about school financial deficit, so they want to buy whichever one is cheaper; (B) the school technology service people are concerned with the maintenance of telescopes, so they suggest to buy the one that has a longer operational life span and is easier to be cleaned and repaired; (C) the professors have a high expectation on the accuracy of observational data, so they prefer the one that has a better quality of image and (D) the students like the one which is easier to manipulate. You will be assigned a role from the four groups of people. Sit with the people who share the same viewpoint. Discuss in groups the pros and cons of each type of telescope. Then argue from your perspective about which type of telescope should be purchased.



Graph 7. The ray diagram of a reflector



Graph 8. The ray diagram of a refractor