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A US-China Interview Study: Biology Students' Argumentation and Explanation about Energy Consumption Issues

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As China and the United States become the top two carbon emitters in the world, it is crucial for citizens in both countries to construct a sophisticated understanding of energy consumption issues. This interview study examines how U.S. and Chinese students compare in explaining and arguing about two critical energy consumption issues: burning fossil fuels and using electricity. In particular, we focused on using scientific knowledge to explain and argue about these issues. Based on relevant literature and our previous research, we developed a model to guide separate assessment and evaluation of students' argumentation and explanation. We conducted clinical interviews with 40 biology majors, including 20 U.S. students and 20 Chinese students. This study generated several important findings. First, Chinese students tended to be less consistent across explanations and argumentation, and their levels of argumentation were lower than their levels of explanation. Second, in comparison to their Chinese counterparts, U.S. students provided more scientific arguments but many fewer scientific explanations. Finally, although all participants were college students and had completed at least one introductory level science course before the interviews, some of their explanations and arguments were based on informal ideas rather than matter and energy. We discuss the possible interpretations of these findings and their implications for teaching and learning of scientific explanation and argumentation in both countries.

Keywords: argumentation, comparative study, energy consumption, explanation

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INTRODUCTION

In this study we compared U.S. and Chinese college students' argumentation and explanation about energy consumption issues. It addresses two goals of science learning: environmental literacy and scientific practices.

First, promoting students' environmental literacy, especially as it relates to energy consumption and global climate change, is essential in the 21st century with the alarming reports about energy production and consumption. The International Energy Agency [IEA] (2013) report provides the following data about energy consumption:

- Since 1971, fossil fuels have been the major energy source for human activities. In 2011, fossil fuels accounted for 82% of the world energy supply.
- Since the Industrial Revolution, annual carbon dioxide emissions from fuel combustion dramatically increased from near zero to over 31 GtCO2 in 2011.
- Nearly two-thirds of global emissions for 2011 originated from just ten countries, with the shares of China (25.4%) and the United States (16.9%) far surpassing those of others.
- Two sectors of energy consumption, transportation and the generation of electricity and heat, account for 64% of global carbon emission.
- Nearly two-thirds of global emissions for 2011 originated from just ten countries, with the shares of China (25.4%) and the United States (16.9%) far surpassing those of all others.

These conditions make it imperative that citizens, especially those in the United States and China, develop a more sophisticated understanding of energy consumption and carbon emissions. However, large-scale survey data show that the general public's understanding of this issue is far from satisfactory. The National Environmental Education and Training Foundation (NEETF) conducted a ten-year, large-scale assessment and found that only 12% of Americans passed a basic quiz on human energy consumption (NEETF, 2002). In another study, Attari and his colleagues (Attari, DeKay, Davidson, & deBruin, 2010) found that people hold a variety of intuitive ideas about electricity usage. Although no large-scale study has been performed in China, a similar discrepancy could be expected, given the fact that science education in China is still largely test-driven and lacks connections to real life experiences (Zhao & Qiu, 2010). Thus, there is an urgent need to empower students to make informed decisions as voters and consumers through enhancing their understanding of energy consumption issues. To this end, more studies are needed to better understand students' existing ideas about energy consumption issues. Therefore, we explored U.S. and Chinese college students' understanding of two issues: burning fossil fuels for transportation and using electricity. We focus on these two issues because they are about two consumption sectors that account for nearly two thirds of global carbon emissions.

Second, the present study focuses on two scientific practices, argumentation and explanation. Scientific practices are central to scientific literacy; they have been emphasized in science education standards in the United States (National Research Council [NRC], 1996) and China (Ministry of Education of People's Republic of China, 2003a; 2003b; 2003c) for many years. Moreover, promoting scientific practices is highlighted in the new reform efforts in both countries. In the United States, the recently released NRC framework and Next Generation Science Standards (NGSS) emphasize the importance of promoting students' science understanding by involving them in scientific practices (NRC, 2012; NGSS Lead States, 2013); Vision and Change in Undergraduate Biology Education calls for engaging college students

"in how scientific inquiry is conducted, including evaluating and interpreting scientific explanations of the natural world" (American Association for the Advancement of Science, 2009). In China, a Ten-year Reform Plan for K-16 Education (Ministry of Education of People's Republic of China, 2010) was released in 2010. Among other goals, the plan aims to release students from exam-oriented education and increase student engagement in scientific practices.

The present study contributes to this effort by focusing on two scientific practices: explanation and argumentation. Explanation has long been recognized as a practice that is crucial for the development of a robust understanding of science (Braaten & Windschitl, 2011). Argumentation is of equal importance as a means for promoting conceptual understanding and critical thinking (Diver, Newton, & Osborne, 2000). Recently, there has been considerable progress in the fields of explanation and argumentation. On one hand, researchers studying students' explanations found that students tend to provide descriptive explanations that fall short of explaining scientific mechanisms (Opfer, Nehm, & Ha, 2012). On the other hand, researchers studying argumentation found that students encounter difficulty constructing sound arguments (McNeill, 2011). Despite the advancement in each research field, research on comparisons and connections between explanations and arguments is still sparse.

To address the challenges, we carried out an interview study to compare U.S. and Chinese college students' explanations and arguments about two energy consumption activities that make the most significant contributions to global climate change (IEA, 2013): burning fossil fuels for transportation and for electricity. Our research question is: How do U.S. students compare to Chinese students in arguing and explaining about energy consumption issues? We specifically focus on the science rather than the social aspects of these two issues.

Conceptual framework

Recently, science education researchers have debated about the distinction between argumentation and explanation. Berland and McNeil (2012) state that a text can be both an argument and an explanation, because arguments and explanations share the same logical structure: claim, evidence, and a warrant, that explains how the evidence supports the claim/conclusion. Alternatively, Osborne and Patterson (2011) suggest that there are differences between explanation and argumentation. In particular, argumentation is about justifying equivocal and uncertain issues. We believe that each of these perspectives has its affordances and challenges. Moreover, assessing explanation and assessing argumentation can be separated by different ways of eliciting responses from students. An assessment of explanation elicits and exhausts students' ideas about how and why things happen, which provides detailed information so that researchers can identify the reasoning pattern behind the student's explanation. An assessment of argumentation focuses on how the student autonomously uses evidence to justify a conclusion; it targets students' understanding of the logical structure of arguments. We propose a model (see Figure 1) that guides the separate assessment of students' ability to argue and their ability to explain.

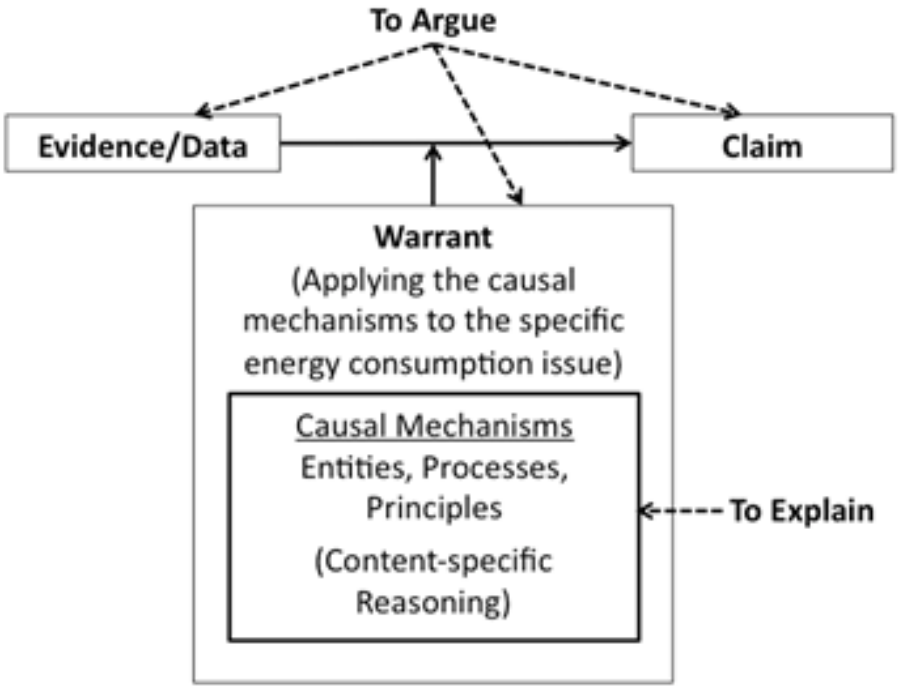


Figure 1. Framework for assessing the ability to argue and the ability to explain.

As shown in the model, we view arguing and the explaining as two dimensions of a complex construct. This complex construct contains a claim, evidence, and a warrant. In addition, the warrant is the application of a scientific mechanism (e.g., matter transformation or energy transformation) to a specific energy consumption issue. The scientific mechanism, which will be elaborated later, reflects a content-specific reasoning pattern—using a specialized way to trace matter and energy in carbon-transforming processes. In the model, the ability to explain focuses on reasoning, whereas the ability to argue targets the understanding of the logical structure.

First, we define explaining as the ability to account for an energy consumption issue. We are interested in the specific reasoning patterns behind students' accounts. When asked to explain a phenomenon, students tend to describe what happens rather than explaining how and why things happen (Braaten & Windschitl, 2011). Therefore, it is important that interviewers use probing questions to fully elicit and exhaust students' ideas, revealing the reasoning patterns behind their accounts. In addition, some of the probing questions must be content-specific, in order to examine whether and how students apply scientific knowledge in explanations. Second, we define arguing as the ability to autonomously 1) generate a logical argument that contains key argument elements (i.e., claim, evidence, and warrant), and 2) incorporate an appropriate scientific mechanism into the argument. In addition, arguments are not evaluated in terms of the correctness of the conclusion, because there could be several appropriate conclusions. Therefore, content-general questions (i.e., questions that do not explicitly require students to apply specific science concepts or principles.) must be used to examine the extent to which students autonomously provide arguments containing all of the key argument elements, and to what extent they identify or incorporate a scientific mechanism

into an argument. When students use a scientific term to argue, it is also important to have them elaborate on the meaning of the term.

Explaining

The assessment of explaining should be designed in ways that enable the identification of the reasoning patterns behind students' accounts about energy consumption issues. To elaborate the approach that we used to identify reasoning patterns, we first discuss the connections among three components: explanation, causal mechanisms, and reasoning.

Braaten and Windschitl (2011) discussed how five models of explanations are used in science classrooms and highlighted the crucial role that causal explanations play in promoting conceptual understanding. At the core of causal explanations are causal mechanisms, which usually contain entities, processes, and sometimes principles that the processes follow (Gopnik & Wellman, 1994). In the case of energy consumption and climate change, scientific explanations are constructed around scientific entities (i.e., matter and energy), processes (i.e., matter transformation, energy transformation, and chemical reactions), and principles (i.e., matter conservation, energy conservation, and energy degradation.). Students may provide explanations that contain a mechanism involving intuitive ideas. For example, instead of using matter and energy to account for events, students may talk about entities such as vital power (Inagaki & Hatano, 2002) and "stuff" (i.e., invisible pieces of material that are continuous rather than having a particulate nature, Johnson, 1998). Instead of explaining chemical reactions, students may describe processes such as conversion between carbon dioxide and oxygen or conversion between energy and matter (Jin & Anderson, 2012a; Jin, Zhan, & Anderson, 2013; Jin & Wei, 2014). Therefore, it is necessary to examine the mechanisms behind the explanations, in order to achieve an in-depth understanding of the students' explanation practice.

We also argue that specific reasoning patterns are always embedded in mechanisms, and thereby explanations. As elaborated above, scientific explanations are constructed based on causal mechanisms that include entities, processes, and principles. The connections among the entities, processes, and principles usually suggest some specific reasoning pattern. Likewise, students' informal explanations are built upon intuitive reasoning patterns. For example, when explaining phenomena such as diffusion, natural selection, and life, scientists use a reasoning pattern that recognizes "emergent processes", whereas students often rely on linear reasoning that assumes the behaviors and processes at a smaller scale should be the same as the pattern at a macroscopic scale (Chi, 2005). When explaining environmental events related to the carbon cycle, scientists use a reasoning pattern that traces matter and energy (i.e., entities) across carbon-transforming processes consistently, whereas students tend to rely on force-dynamic reasoning that is about how an actor (e.g., a plant) uses its enablers (e.g., water, sunlight, and soil) to grow or move (Jin & Anderson, 2012a).

Therefore, we evaluate students' ability to explain in terms of the reasoning patterns embedded in explanations. More specifically, we identified reasoning patterns by identifying and examining the mechanisms (i.e., entities, processes, and/or principles) of explanations. In previous research, we developed learning progression frameworks that depict students' understanding of matter (Mohan, Chen, & Anderson, 2009) and energy (Jin & Anderson, 2012a; Jin & Anderson, 2012b) in coupled environmental and human systems. We integrated the ideas of these frameworks, based on which we developed an explanation framework that describes qualitatively different reasoning patterns that students use to explain burning fossil fuels and using electricity. It is presented as follows:

Level 1. Force-dynamic reasoning. Force-dynamic reasoning is embedded in both the English language (Pinker, 2007) and Chinese language (Lai & Chiang, 2003). In our previous research, we found that students used force-dynamic reasoning to interpret and explain the material world around them (Jin & Anderson, 2012a). Therefore, level 1 contains force-dynamic explanations that describe the relations among machines and material objects. More specifically, a force-dynamic explanation is about how an actor (e.g., a machine, a vehicle, or flame) uses enablers (e.g., fuels, air, or other materials) to move or work. For example, cars or machines are actors, because they have the ability to move. In order to move, they also need help from enablers such as gasoline or electricity. As one can see, the entities (i.e., actors and enablers) and processes (movement) are all at the macroscopic scale.

Level 2. Hidden mechanism reasoning. Responses at level 1 explain phenomena in terms of observable changes that are at the macroscopic scale, whereas responses at level 2 explain phenomena in terms of hidden mechanisms. Level 2 responses also differ from level 3 responses in that they are about two intuitive entities rather than matter and energy. First, students understand matter as a kind of "stuff". It is important to note that "stuff" differs from the scientific concept of matter in that it does not entail "the particulate nature of matter" (Johnson, 1998). Instead, stuff refers to invisible pieces or particles that are the same as the macroscopic material objects but in smaller sizes. Second, students understand energy as a type of "vital power". They usually rely on macroscopic experiences to infer what kinds of things provide vital power. For example, students may think that air provides energy for the flame because they observe that flame goes out when there is no air. They may think that vital power can be destroyed, because fuels are often "consumed" to power vehicles and machines. They may also think that fuels become the waste material or pollution after their energy is consumed, because they observe exhaust gases emitted.

Level 3. Matter-energy mechanism reasoning. Responses at level 3 explain macroscopic phenomena in terms of entities such as atoms, molecules, or forms of energy, but they often contain content errors. Some common errors are: matter-energy conversion, chemical transmutation, and energy conservation without recognition of heat dissipation.

Level 4. Reasoning of matter transformation and energy transformation. Responses at level 4 explain macroscopic phenomena in terms of scientific mechanisms, that is, matter transformation and/or energy transformation. Matter transformation is about how atoms of the reactants rearrange to form products. In this process, the total amount of each kind of atoms is conserved. Therefore, the mass of the reactants equals the mass of the products. Energy transformation is about energy changes from one form to other forms, with heat dissipation.

Arguing

Whereas the assessment of explaining targets the reasoning patterns, the assessment of arguing focuses on students' understanding of the logical structure of arguments—the extent to which students autonomously construct an argument that contains all of the key elements and incorporates a scientific mechanism into the argument. Osborne and Patterson (2011) point out that argumentation should be about controversial or uncertain issues. Therefore, in argumentation tasks, we provided two opposing views and asked students to justify the view that they believed was true.

Researchers often use the Toulmin (1958) model to evaluate the structural quality of students' arguments. According to Toulmin, an argument usually contains a claim (statement being argued), data (evidence used to support the argument), warrants (logical statements that bridge the gap between claim and data), backing

(statements that support warrants), and rebuttals (statements indicating circumstances when the claim does not hold). In the present study, we specifically focus on three components: claim, data, and warrants. Application of Toulmin's argument model is challenging because students' arguments often cannot be categorized into argument elements in a clear-cut manner. In a previous study, we developed a rubric that solved this problem (Jin, Mehl, & Lan, 2015). According to the rubric, students' arguments were first separated into causal arguments and noncausal arguments. The Toulmin model was used to evaluate causal arguments into different levels, as it lays out the logical components of causal arguments. Walton's (1996) "argument schemes" depict different structures of noncausal arguments and, therefore, were used to develop the lowest level of the argument rubric. In the present study, we used this rubric as the argumentation framework to evaluate students' arguments. It is presented below.

Level 1. Informal arguments and claim-only arguments. Informal arguments are noncausal arguments used in everyday life. There are five types of informal arguments. 1) Arguments from example use an example to justify a generalized conclusion. 2) Arguments from authority claim that the conclusion is true because an authority said so. 3) Arguments from popularity state that the conclusion holds true because many people believe it. 4) Arguments from consequence claim that a conclusion is true/not true, because there exists a positive/negative consequence. 5) Claim-only arguments only contain claims and do not contain evidence or warrants.

Level 2. Arguments based on a simple cause-and-effect relationship. An argument at level 2 uses evidence to justify a claim. The justification is based on a simple cause-and-effect relation, which is usually based on common sense or intuition rather than matter or energy. For example, many students state that ethanol produces less carbon dioxide than gasoline because ethanol is made from corn, and corn is natural. This argument is based on a simple cause-and-effect chain: natural things cause less damage (e.g., carbon dioxide) to the natural environment.

Level 3. Arguments based on mechanisms of matter and energy (with common errors or which do not specify energy/matter transformation). An argument at level 3 contains claim, evidence, and an explicit warrant. The warrant explains the link between evidence and claim in terms of a matter/energy causal mechanism. However, students either cannot fully explain the causal mechanism or provide explanations that have content errors. For example, some students stated that fluorescent light bulbs provided more light with less energy input because they are more energy efficient. However, when the researcher asked them to explain the meaning of energy efficiency, they could not provide a correct explanation. In this case, the students used a mechanism (i.e., energy efficiency), but could not elaborate on its meaning.

Level 4. Arguments based on the scientific mechanism—energy transformation and/or matter transformation. An argument at level 4 contains claim, evidence, and warrant. The warrant explains the link between evidence and claim in terms of a scientific mechanism, that is, matter transformation and/or energy transformation.

METHODS

Participants

We are interested in how students explain and argue about energy consumption issues. In particular, we focused on how students use the knowledge of matter and energy to explain and argue about burning fossil fuels and using electricity. Matter and energy are key topics in high school curriculum in both the United States and China. In the present study, we collected interview data from college students who had not only been exposed to matter and energy in high school, but also had

completed at least one course that provided a more in-depth exploration of these concepts (i.e., introductory biology or introductory chemistry). Our participants included 20 U.S. college students (9 females and 11 males; 1 Asian American, 1 Hispanic American, and 18 non-Hispanic White American) and 20 Chinese college students (15 females and 5 males; all Han Chinese). The U.S. students were second or third year biology majors from two public universities. The Chinese students were third year biology majors from two national universities.

Interview tasks

We used a clinical interview to collect data. We first developed an English-language interview protocol. Then, the first author, whose native language is Chinese, translated the interview protocol into Chinese. To confirm the accuracy of the translation, we asked two science education researchers, who understand both Chinese and English, to review the Chinese protocol. Based on their comments, we revised the Chinese protocol to ensure that the interview questions fit Chinese culture and would make sense to Chinese students. The interview protocol is provided as a supplementary material at the journal website. It contains two sets of interview tasks: argumentation tasks and explanation tasks. Students completed the argumentation tasks before the explanation tasks, because the content-specific questions used in explanation tasks may provide hints that allow students to identify the concepts/principles to be used in arguments.

Argumentation Tasks. Two tasks were used to assess students' ability to argue. In each task, the student was first provided with two opposing arguments that contain a claim and a piece of evidence that is vaguely described. To complete each task, students indicated who they agreed with and why. The first task is about using different types of fossil fuels to power cars. The second task is about whether it is possible that a 13W fluorescent light bulb gives off about the same amount of light as a 60W incandescent light bulb. The researcher used only content-general questions in the interview in order to assess whether the student could autonomously construct arguments with all key argument components. Take Task 1 as an example. The student is first provided with a picture of a gas station that provides ethanol and a description of the scenario: "Karen wants to buy a new car with a small carbon footprint. She has heard about ethanol-powered cars but does not know how they work. So, she asked her friend for suggestions. One friend, Tom, said using ethanol to replace gasoline would result in less carbon emission because ethanol is a type of green energy source. The other friend, David, said using ethanol to replace gasoline will not result in less carbon emission because both of them are fuels." The interviewer asks content-general questions to elicit students' logical arguments. Some examples of these questions are: Who do you agree with? Do you think David used sufficient evidence to support his claim? Can you modify the argument to make it strong enough?

Explanation Tasks. Two explanation tasks were used to assess students' ability to explain. They were modified from a previous study on explanation (Jin, Hokayem, Wang, & Wei, in press). For each task, we used both content-general and content-specific questions to elicit and exhaust students' ideas. For Task 1 required students to explain the event of a car using gasoline to move. We asked three sets of questions, with each set containing both content-general and content-specific questions. The first set of questions asked students to explain why gasoline instead of water and carbon dioxide is used to run the car. It elicited students' ideas about the relationship between matter and energy. The second set of questions asked students to explain where the energy came from and where it went when the car was stopped. It was used to elicit students' ideas about changes in energy. The last set of questions asked students to compare the mass of the consumed gasoline with

the mass of exhaust gases. It elicited students' ideas about changes in matter. Task 2 was modified from a written item designed by researchers at Arizona State University (Swackhamer, 2005). It required students to explain how energy changes in a scenario of using a refrigerator to cool down the air in a closed room.

Data analysis

The interviews were video-recorded and then transcribed. Using the approach of quantifying verbal data (Chi, 1997), we analyzed the transcripts in three steps. We first segmented each interview into six units of analysis (i.e., episodes) based on the structure of the interview protocol (Table 1). The segmentation resulted in 2 argumentation episodes and 4 explanation episodes.

Table 1. Segmentation of each interview

Interview Tasks	**Segmentation**
Argumentation Task 1. Different fossil fuels	Argumentation Episode 1
Argumentation Task 2. Light bulbs	Argumentation Episode 2
Explanation Task 3. Car running (Question Set 1)	Explanation Episode 1
Explanation Task 3. Car running (Question Set 2)	Explanation Episode 2
Explanation Task 3. Car running (Question Set 3)	Explanation Episode 3
Explanation Task 4. Refrigerator (energy)	Explanation Episode 4

Developing the Initial Rubrics. Based on the argumentation framework and explanation framework, we developed a rubric for argumentation tasks and a rubric for explanation tasks. Each rubric contains a detailed level description and exemplar interview episodes for the two energy consumption issues.

Developmental Coding. The main purpose of developmental coding was to enhance the validity through iterative cycles of coding and revision of the coding rubrics. The first author and the second author used the rubrics to score each English interview independently. The first, third, and fourth authors used the rubrics to code each of the Chinese interviews since it was their native language. Disagreements in coding were constantly revised and the rubrics were refined to achieve better conceptual clarity and empirical applicability. In this process of developmental coding, we found that differentiating two adjacent levels was a major challenge. Therefore, we developed a set of keys to explain the distinction between two adjacent levels.

Full Coding. We used the final rubrics to code the data. Each interview has 6 scores. For the final round of coding, we calculated Cohen's Kappa to measure interrater reliability. For the Chinese interviews, the Kappa values were 0.73 for argumentation and 0.82 for explanation, indicating substantial for the U.S. interviews, the Kappa values were 0.86 for argumentation and 0.82 for explanation, indicating almost perfect agreement (Landis & Koch, 1977). Then, all researchers discussed and resolved the disagreements in the final coding.

FINDINGS

We compared U.S. and Chinese students from three aspects: explaining performance, arguing performance, and the consistency between explanation and argumentation.

Explaining performance

The explaining performance results of U.S. and Chinese students is presented in Figure 2.

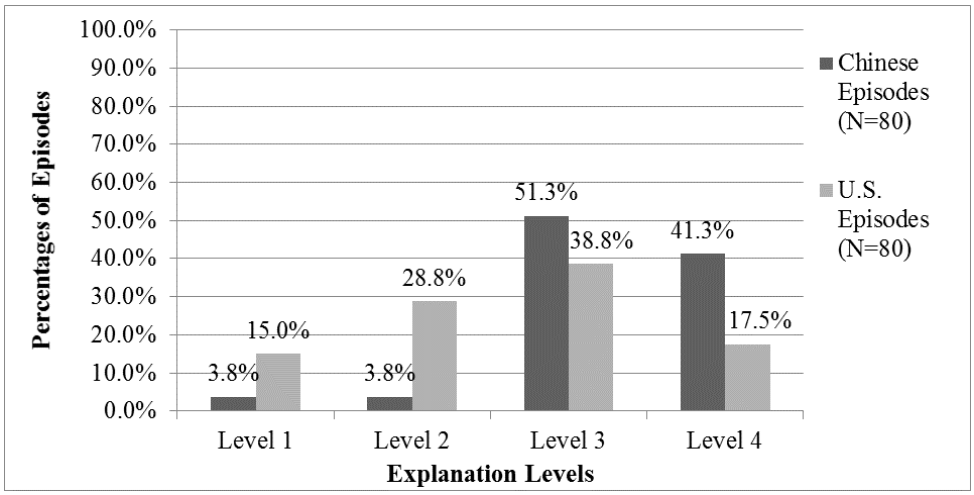


Figure 2. Distribution of responses at different explanation levels.

About 92.6% of Chinese explanations were scored as Level 3 and Level 4; these explanations were built upon ideas about matter and/or energy. Only about half of the U.S. explanations (56.3%) were about matter or energy, and the rest of the explanations were about informal ideas (43.8%). In addition, 41.3% of the explanations in Chinese interviews and 17.5% of the explanations in U.S. interviews were scientific explanations. The above evidence suggests that Chinese students performed better than U.S. students in explanation.

Arguing performance

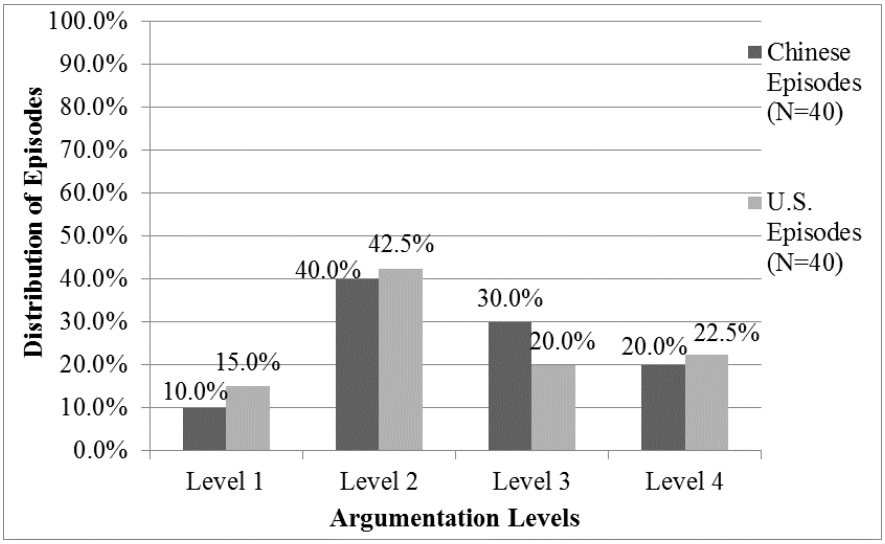


Figure 3. Distribution of responses at different argumentation levels.

The arguing performance of U.S. and Chinese students is presented in Figure 3. For each group, about half of the arguments fell in Level 2 (42.2% of U.S. arguments and 40.0% of Chinese arguments), and some students provided noncausal arguments (Level 1). While Chinese students provided more arguments about matter and/or energy (i.e., Level 3 and Level 4 arguments together), U.S. students provided more scientific arguments (i.e., Level 4 arguments).

Consistency across explanation and argumentation

We also compared the consistency across the two practices. In particular, we were interested in the extent to which students consistently draw on content knowledge when explaining and arguing about energy consumption issues. In both the argumentation framework and the explanation framework, Level 1 and Level 2 are about informal explanations/arguments, in which content knowledge does not play a role; Level 3 and Level 4 are about explanations/arguments including ideas about matter and energy. Therefore, we compared the consistency of students' practices by examining if matter/energy was used to argue or explain the same energy consumption issue. For the issue of burning fossil fuel, each student's interview contains three explanation episodes. If the student used matter/energy in at least one explanation episode, we assumed that student demonstrated the ability to use matter/energy knowledge in explanation. As such, we identified three patterns of consistency (see Figure 4):

- Being Inconsistent: 1) The student provides an informal argument (Level 1 or Level 2) and a matter/energy explanation (Level 3 or Level 4) for an energy consumption issue; or 2) the student provides a matter/energy argument (Level 3 or Level 4) and an informal explanation (Level 1 or Level 2) for an energy consumption issue.
- Being Consistently Low: The student provides an informal argument (Level 1 or Level 2) and an informal explanation (Level 1 or Level 2) for an energy consumption issue.
- Being Consistently High: The student provides a matter/energy argument (Level 3 or Level 4) and a matter/energy explanation (Level 3 or Level 4) for an energy consumption issue.

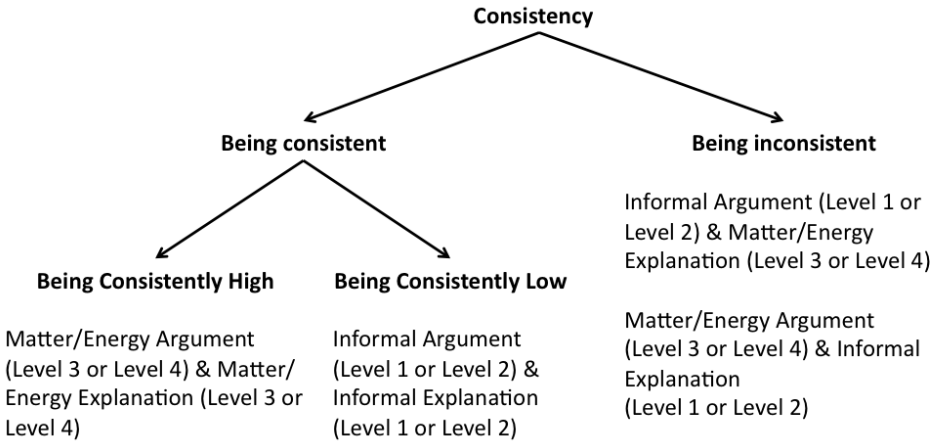


Figure 4. Patterns of consistency across argumentation and explanation.

In the paragraphs that follow, we use examples from interviews to present the three patterns of consistency.

Being Inconsistent. Students demonstrated inconsistency in argumentation and explanation. Some of these students provided informal explanations but matter/energy arguments, while others provided matter/energy explanation but informal arguments. Here, we present a pair of interview excerpts to illustrate the case where a student's argumentation level is lower than her explanation level. The Chinese student, DLX, provided an informal argument and a matter/energy explanation for the issue of burning fossil fuels. In the argumentation task, she provided two arguments regarding whether using ethanol to replace gasoline would cause less carbon dioxide emission. One argument is an argument from authority (Walton, 1996): "Ethanol releases less carbon, because many newspapers report so." This is a Level 1 argument. The other argument is a Level 2 argument: "Ethanol releases less carbon, because it is made from foods." This argument is based on a simple cause-and-effect relationship: Things made from natural resources cause less damage to the atmosphere (carbon dioxide is treated as damaging). Therefore, we scored DLX's argumentation episode as Level 2, the highest level she was able to demonstrate in the interview. In the explanation task, DLX provided explanations that are about matter and energy. In the episode about connections between matter and energy, she recognized that gasoline provided energy because it contained carbon-containing organic substances and that carbon-containing substances contained carbon, hydrogen, and oxygen. However, she did not identify the unique structure of carbon-containing organic substances—they provide energy because they all contain C-C and/or C-H bonds. Therefore, this episode was coded as Level 3. In the episode about matter, DLX used matter-energy conversion, a common misconception, to explain changes in matter: "Part of gasoline became heat energy and the rest became gases emitted from the tailpipe." Therefore, DLX received Level 3 for the episode about matter in burning fossil fuels. In the episode about energy, DLX recognized that the kinetic energy finally dissipated into the environment as heat. Therefore, she received Level 4 for the episode about energy in burning fossil fuels. In summary, DLX provided an informal argument and matter/energy explanations about the issue of burning fossil fuels. As one can see, although DLX used informal ideas to justify her arguments about burning fossil fuels, she used ideas of matter and energy to explain phenomena of burning fossil fuels.

Burning Fossil Fuels: Argumentation task (Level 2)

Researcher: Do you agree with Xiao Li?

DLX: Yes. I agree. Many newspapers report that ethanol as fuel or half ethanol and half gasoline as fuel to reduce carbon emission [Evidence 1]. Also, ethanol can be made from foods [Evidence 2]. So, I think it's a green energy source, so I think it can reduce carbon emission [Warrant 2]. I support Xiao Li. *(Level 1)*

Researcher: Do you think Xiao Li has sufficient evidence?

DLX: What is evidence?

Researcher: The evidence is the reasons for your conclusion.

DLX: I think he does not have sufficient evidence. I think if I want to buy, I will buy an ethanol-powered car, because ethanol is renewable energy source. After you consume the gasoline, it is gone. *(Level 2)*

Burning Fossil Fuels: Explanation task

(Episode: Connections between matter and energy; Level 3)

Researcher: Why can gasoline provide energy?

DLX: It provides chemical energy, which becomes kinetic energy to power the car.

Researcher: Why can it provide chemical energy?

DLX: Because it burns. It burns and produces energy. It has carbon.

Researcher: Do you think it provides chemical energy because it has some special structure?

DLX: It is carbon-containing organic materials.

Researcher: What do you mean by carbon-containing organic substances?

DLX: Carbon-containing organic materials contain carbon, hydrogen, and oxygen. Carbon has four positive charges.

(Episode: Matter; Level 3)

Researcher: Ok. I will ask you another question. A car consumed a gallon of gasoline. We managed to collect all exhaust gases from the tailpipe. Could you compare the mass of the consumed gasoline and the mass of exhaust gases? Which one is larger?

DLX: I think gasoline weighs more, because it releases heat.

Researcher: What do you mean by that? You mean part of the gasoline became heat?

DLX: Yes. So the exhaust gases weigh less.

(Episode: Energy; Level 4)

Researcher: Do you think the car has energy when it is running?

DLX: Yes. Kinetic energy.

Researcher: So, where does that kinetic energy go, when the car stops?

DLX: It becomes heat due to the friction between the tires and the ground.

Being Consistently High. Some students used matter and/or energy to construct both arguments and explanation. We define this pattern as being consistently high. As shown in the example below, a U.S. student, Richard provided a Level 4 argument. He claimed that using ethanol to replace gasoline would not result in less carbon emission, and then justified this claim by stating that two parts of carbon emission should be considered: carbon emission from burning ethanol and carbon emission due to using gasoline used to produce ethanol. In the explanation task, Richard used matter and energy to explain phenomena. When explaining the differences between fossil fuels and materials that do not provide energy (i.e., connections between matter and energy), he associated carbon-hydrogen bonds with energy, but also mistakenly stated that energy is released when bonds break (Level 3). When explaining changes in energy, he stated that the potential energy provided by gasoline was released and turned into kinetic energy, and finally dissipated into the environment through friction (Level 4). When explaining changes in matter, he stated that the mass of the gasoline equals the mass of the exhaust gases because of the conservation of mass in chemical reactions. He applied the conservation of mass law, but did not identify oxygen as a reactant involved in combustion. Therefore, his explanation about matter was scored as Level 3. As one can see, Richard consistently used ideas of matter and energy to explain and argue about the issue of burning fossil fuels.

Burning Fossil Fuels: Argumentation task; Level 4

Richard: I disagree with Tom, but I'm not sure that I agree with David either.

Researcher: So let's talk about Tom. You disagree with Tom. So what is wrong in his argument?

Richard: Ethanol isn't going to result in less of a carbon emission because ethanol isn't necessarily a green energy resource, it is an alternative energy resource but it's still will result in a carbon footprint [Claim], there is still more carbon used to process the ethanol to harvest the corn to make the ethanol than other traditional or non-traditional for of energy [Evidence].

Researcher: And you said you don't 100% agree with David, right?

Richard: Right.

Researcher: So, what is the reason?

Richard: I don't know. I guess I would agree with David…yeah, I would, because using ethanol to replace gasoline would not result in less carbon emission [Claim] because both gasoline and ethanol are fuels [Evidence].

Researcher: So, why? How is that about carbon emission?

Richard: So, when you burn ethanol, you might not have as much direct carbon emission from the vehicle, but you also have to take into account all of the gasoline that's going into producing the ethanol [Warrant].

Burning Fossil Fuels: Explanation task

(Episode: Connections between matter and energy; Level 4)

Researcher: Why do people use gasoline instead of water to run their cars?

Richard: So gasoline is made out of very long hydrocarbon chains and you get the energy by putting the gasoline under pressure and lighting it, which is breaking those carbon chains, and then you harvest that energy to power your car. You can't use water because if you look at it…. But when you look at a water molecule versus a hydrocarbon molecule, a hydrocarbon has hundreds and hundreds of hydrogen and carbon bonds, whereas in a water molecule, you have oxygen bonded to hydrogen or sorry, two hydrogen bonded on oxygen and the bonds are nearly, there's not enough nearly as much energy in them as you do have in the carbon bonds and there's not as many bonds to break. So that's why my understanding of why people use gasoline over water.

(Episode: Energy; Level 3)

Researcher: Does a car need energy in order to run?

Richard: You have to have an input of energy. Yes, in the sense that, you put something in the car that is going to be manipulated to provide the energy, because what you do with the gasoline is it gets combusted in the engine and then the combustion of that provides the energy for the car.

Researcher: So, do you think energy is like being produced by combustion?

Richard: So, when you have the gasoline in the car, that's potential energy. Then the engine takes up potential energy and breaking the bonds, and the combustion in the gasoline turns it into kinetic energy.

Researcher: So when the car was running, it had kinetic energy, right? Where did that kinetic energy go [when the car stopped]?

Richard: Well. It's lost through the movement of the car.

Researcher: What do you mean by 'it's lost'?

Richard: You have to, you provide a force that's the gasoline's moving the car forward and then, you know, it's lost; it's not lost, it just transits into other types of energy, like you lose some through friction of the tires on the road, and then you have an emission; it's not lost.

(Episode: Matter; Level 3)

Researcher: Now let's talk about gasoline. A car used one gallon of gasoline to run 35 miles. Assume that we can actually figure out a way to collect all the exhausted gases and other exhausted stuff. Now, I want you to compare the gasoline you used with the exhausted gases and exhausted materials. Compare the mass of them.

Richard: Well they'd be the same, because when you have a chemical reaction which… When you combust something that is a type of chemical reaction, you have to have the same amount of molecules, compounds, elements on each side.

Being Consistently Low. Some students provided both informal arguments and informal explanations about the same energy consumption issue. These students received Level 1 or Level 2 for both argumentation and explanation. We define this pattern as being consistently low. We present a pair of interview excerpts from a

Chinese student, YHR. In the argumentation episode, YHR stated that the two light bulbs had different wattages, so they emit different amounts of light. This justification is based on a simple cause-and-effect chain: different inputs (wattages) lead to different outputs (light). She was not able to specify how different wattages cause different light emissions. In other words, she could not provide a warrant to link the evidence to the claim. Therefore, YHR's argument was scored as Level 2. In the explanation task, YHR provided a force-dynamic explanation about using electricity (Level 1): "The room is closed, and the cold air comes out from the refrigerator. Therefore, the room temperature will decrease." As one can see, YHR consistently used informal ideas to explain and argue about the issue of using electricity.

Using Electricity: Argumentation task; Level 2

Researcher: Do you agree with Xiao Qian?
YHR: Yes. It's like what I'm thinking.
Researcher: Do you think she has a good reason?
YHR: I think so. The wattages are different [Evidence], so the amounts of light given off are different [Claim]. Oh, it's a bit too certain.
Researcher: So, how you revise the argument, in order to make it more appropriate?
YHR: I think the argument is not good, but I don't know how to revise it.
Using Electricity: Explanation task; Level 1
YHR: I think the temperature will decrease.
Researcher: Why?
YHR: It's a closed room, right? So, the cold air comes out. The cold air interacts with the warm air in the room.
Researcher: So, that causes the temperature to drop?
YHR: Yes.

Consistency Results. The consistency patterns in U.S. and Chinese interviews are presented in Figure 5.

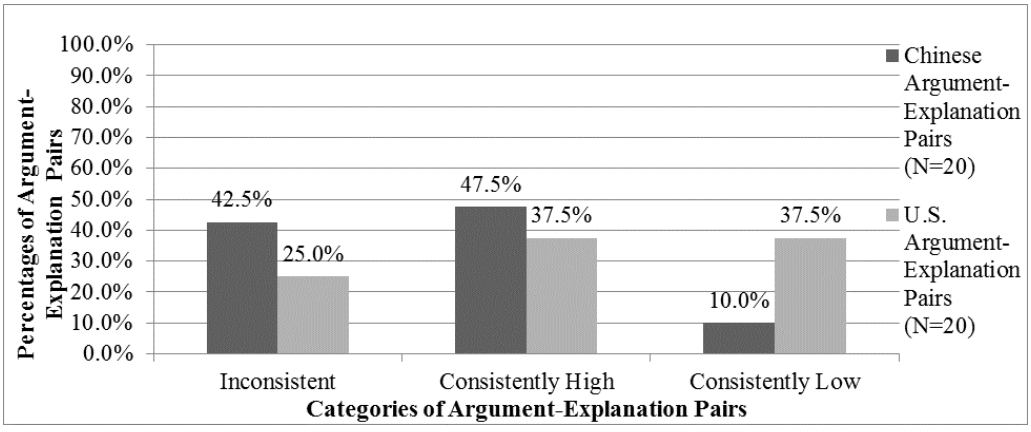


Figure 5. Consistency across explanation and argumentation.

The figure suggests that U.S. students tend to be more consistent across explanation and argumentation. They demonstrated consistency for 75.0% of the explanation-argumentation episode pairs, whereas Chinese students demonstrated consistency in 57.5% of the pairs. It is also important to note that the argumentation level was lower than the explanation level for all inconsistent pairs among Chinese

students, suggesting that Chinese students were better at explanation than argumentation. However, the same pattern did not appear in U.S. interviews.

CONCLUSION AND DISCUSSIONS

In this comparative study we evaluated U.S. and Chinese college students' explanations and argumentation about energy consumption issues. It makes several important contributions to science education in the United States and China. First, based on different ideas about the distinction and connections between argumentation and explanation (Berland & McNeill, 2012; Osborne & Patterson, 2011), we developed a model that treats argumentation and explanation as two dimensions of a complex construct. This model guided us to use different approaches to elicit and evaluate students' explanations and arguments about the same energy consumption issues. Researchers could modify and use this model to investigate students' argumentation and explanation regarding other science topics.

Second, the results provide implications for science education in both China and the United States. The results show that Chinese students tended to be less consistent across explanations and argumentation, and that their levels of argumentation were lower than their levels of explanation. One possible reason is that Chinese teachers seldom have the luxury to engage their students in scientific inquiry practices such as argumentation (Zhang, et al., 2003). On the one hand, the exam-oriented education system has put great pressure on teachers to improve their students' test scores (Zhao & Qiu, 2010). Many teachers view lectures as the most "efficient" way to transmit a large quantity of content in a short time period. As a result, they seldom teach practices such as argumentation in class. Additionally, classroom sizes are usually large (about 40 or more students), precluding teachers from carrying out more student-centered activities. Therefore, a joint effort by the government and local schools is needed to support teachers in engaging their students in scientific practices.

For U.S. students, the results show that about half of the explanations (43.8%) were informal. Although U.S. students provided more scientific arguments than their Chinese counterparts, they provided many fewer scientific explanations. One possible reason for this finding is related to how scientific knowledge is taught in the U.S. and Chinese science classrooms, that U.S. teachers seldom emphasize using reasoning patterns to organize knowledge, whereas Chinese teachers often explicitly teach the logical thinking beneath the content in class. Researchers studying U.S. teachers' classroom teaching practice found that teaching the rationale beneath the science concepts, principles, and facts is very challenging for teachers (Roth et al., 2011). Chinese teachers often explicitly teach the logical thinking behind the content in class (Jin, Wei, Peng, & Hokayem, 2015). Therefore, we suggest that teacher education and professional development programs engage pre-service and in-service teachers in a more extensive focus on the ideas and reasoning patterns behind the science content.

In conclusion, this interview study has generated an in-depth interpretation of students' argumentation and explanation. Although the results about the differences between the U.S. and Chinese students cannot be generalized to a larger population due to relatively small sample size of this study, our coding rubrics did capture important differences between explanations and argumentation. Based on the findings of the present study, we will carry out future research in two areas. First, we will use the explanation and argumentation frameworks developed in this study as a foundation for a large-scale comparative study in the United States and China. Second, we will work with instructors of introductory level science courses on using inquiry-based approaches to promote students' argumentation and explanation.

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