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Analysis of Energy Literacy and Misconceptions of Junior High Students in Taiwan

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Abstract: Decision-making regarding energy determines carbon emissions and the severity of climate change. Energy literacy plays a crucial role because well-informed citizens can support the design and implementation of smart and forward-looking policies. Research has shown that people hold misconceptions about energy, and for young students these may persist into adulthood. Thus, this study is to understand the energy literacy of junior high school students in Taiwan and what their misconceptions are as well as why and how they hold these. Energy literacy scales (ELS) were developed and served as the basis for a survey of 1652 students in five regions of Taiwan, in which most indicators for knowledge were designed corresponding to common misconceptions in the scientific and social context of energy issues. Through analyzing the survey questions and survey results, interview questions were designed and 10 students were interviewed to identify their misconceptions. A "conceptual logic map" model was developed for demonstrating the sources and patterns of misconceptions and their linkages. Potential educational strategies were then proposed, showing the applicability of the model. The combination of concept-oriented energy literacy surveys, interviews, and the conceptual logic map was proven to be an effective design for misconception identification and treatment.

Keywords: energy literacy; misconception; conceptual logic map; junior high school; Taiwan

1. Introduction

Climate change is one of the most critical challenges that human beings face at this stage of human development. As the Paris Agreement was signed by most of the parties of UNFCCC in 2015 and then ratified by more than 55% of parties with enough percentage of global GHG emissions and became effective in late 2016, the urgent need for carbon reduction will dominate the global economy in the following decades. To combat climate change and meet the goal of limiting the global average temperature increase to "well below 2 °C", effective mitigation strategies and aggressive implementations are needed. Energy-related GHG emissions cover more than 60% of the global inventory according to different reports by international organizations [1,2]. For most countries, a transition of energy systems to low-carbon ones is key to accomplishing mitigation goals [3]. Clean energy or low-carbon energy is being streamlined in the global economy.

Thus, energy is a defining issue in this age. Selections of energy determine not only the extent of threat to the planet because of anthropogenic carbon emissions, but also the health and sustainability of the economy and even national security [4]. Energy issues are complicated and need to be analyzed in a systematic way. For example, carbon reduction in the electricity sector is one of the priorities for climate change mitigation, as most electricity is generated from fossil fuels in many countries. However, the rapid increase of electricity from wind and the solar photovoltaic (PV) cannot support the transition to meet the <2 °C goal [3]. More issues related to market mechanisms, such as economic incentives, carbon pricing, and corresponding benefit/cost analysis, need to be incorporated [5]. That is, energy is not just about science, but also about daily lives, along with related economic and social issues.

Thus, energy is about decision-making; hence, energy literacy plays a crucial role as well-informed and well-educated citizens are the basis for the design and implementation of smart and forward-looking policies. In addition to support from technological innovation, energy-literate citizens, instead of decision-makers, who can engage in the decision process and commit to action, help bring about a successful paradigm shift in terms of energy use, e.g., from a heavy reliance on fossil fuels to low-carbon renewable energy sources [6]. It was argued that knowledge about energy is required to make people citizens with basic competence [7]. However, energy literacy is not just about knowledge, which is cognitive, but also aspects related to affect and behavior. People with energy literacy are expected to take responsible actions according to their assimilated knowledge and constructed value [8].

Energy literacy has been studied in many countries in the world for different purposes. Similar to those research works related to environmental literacy, there are three traditional aspects: cognitive, affective, and behavioral were taken for framing the energy literacy [9–11]. As mentioned above, with awareness or knowledge serving as the base, together with specified attitude, responsible behavior can be expected. Knowledge related to energy was of major concern in many studies [10–12]. In some studies, the general public's perceptions and knowledge about energy were compared with those of experts, with reasons for the differences examined [13]. Behavioral models were also introduced and applied to related studies, linking the relationships between knowledge, attitude, and behavior [14,15].

It was argued in the literature that misconceptions may result in biased communication, leading to the general public's preference for or objection to specific energy options [16]. Sometimes people tended to face misinformation about climate change and energy, which looks like science but in essence is propaganda, politically embedded in the context of information sources [17]. Misconceptions, i.e., knowledge or concepts that are not consistent with those accepted by the scientific community, caused by this or other reasons were then of major concern [18,19]. In general, misconceptions related to energy are common and may lead to erroneous information, misunderstandings, false interpretations of energy issues, and insufficient support for sustainability-oriented energy policies. How to identify and treat misconceptions was very important in the viewpoint of education and policy communication [20]. However, an ideal framework for identifying and demonstrating misconceptions and corresponding sources cannot be found in the literature.

In this paper, an energy literacy scale was developed for the purposes of understanding Taiwanese junior high school students' knowledge, attitude, and actions regarding energy, in which most indicators for knowledge were designed to correspond with common misconceptions about energy issues. A survey was then conducted to determine the energy literacy status, followed by interviews identifying the students' misconceptions. A "conceptual logic map" model was developed for demonstrating the sources and patterns of misconceptions, which can be used as a diagnostic and analysis tool for educational purposes.

The rest of the paper is organized as follows: Section 2 reviews the literature related to energy literacy and misconception. The methodology is presented in Section 3, including the development of energy literacy scales, a questionnaire, and conceptual logic maps for identifying misconceptions. Data collected from the surveys will be analyzed in Section 4. Misconceptions and these maps will be shown and discussed based on interviews in Section 5. Section 6 concludes this paper.

2. Literature Review

2.1. Energy Literacy

According to *Webster's Third New International Dictionary*, "literacy" was originally defined as competence in reading and writing. The meaning of literacy then expanded to include education and broad knowledge in multiple fields. In other words, there is not a universal definition for literacy, which goes beyond the ability to read and write to encompass the capacity of people to read and understand things [21,22]. Thus, literacy is not about "all or none", but the process of filling up an empty bottle, including gaining and utilizing knowledge, possessing an objective attitude, being able to assess and apply information, and making the right decisions [23].

Since the Industrial Revolution, energy has played a crucial role in the development of human civilization. In fact, the dominating industrial–commercial economy in our age relies heavily on the use of fossil fuels, as they are abundant, convenient, and widely accepted, so pricing is easily controlled. However, at the same time, mining, refining, transporting, and the use of fossil fuels has resulted in tremendous deterioration of environmental quality globally, e.g., climate change. These globalized energy policies and economic systems have been built step by step by citizens, scientists, corporations, and decision-makers of the world's countries. This reminds us that energy literacy should be emphasized because when facing the complicated and confusing situations, energy-literate citizens can make considerate, responsible decisions [21].

Thus, energy literacy has been discussed widely in the literature, focusing not only on scientific knowledge, but also on citizens' participation and political support in the social context [24,25]. The energy literacy developed by the Department of Energy of the USA (USDOE) is among the most representative ones, in which physical and biological processes, energy flow and earth systems, economic perspectives, and energy decisions are emphasized [26]. In recent years, energy literacy scales have been developed according to the basic categories of knowledge, attitude, and behavior, although in some studies these were modified in terms of wording or by mixing in some other ideas such as lifestyle or civic responsibility [27–29]. Following these, surveys were carried out with different groups of people in different countries. Knowledge scores were of major concern and were discussed together with performance from the affective and behavioral perspectives. For example, a survey of over 3000 high school students in the USA indicated that the students got very low scores for knowledge and fair scores in behavior, although they were concerned about energy issues [9]. In Taiwan, an energy literacy survey using contextualized assessment questionnaires concluded that 600+ high school students' energy literacy was very low; their basic scientific knowledge was found to be better than their energy-related knowledge. Gaps were identified between their understanding of basic science and that of energy. Students' knowledge about renewable energy was found to be lower than that of experts in Greece [13]. However, also in Taiwan, another survey about energy literacy generated different results in that the 2400 secondary students had high energy literacy, with some impacts from age, gender, and socioeconomic status [11].

Thus, whether students' performance in energy literacy was high or low was not the key issue. On the contrary, data analysis and strategic discussion are more important for energy education. Basic concepts of energy literacy in primary education were discussed and expected to be as concrete as possible as children were still in the "concrete stage" [30]. For secondary and higher education, constructive learning strategies can be employed. For example, a study in STEM education emphasized that, to understand how renewable energy works, people need to understand the basic mathematics, science, engineering, and technology, together with the relationships among them [31]. It other words, training in understanding and applying the scientific method to energy issues was the central issue.

2.2. Misconceptions about Energy

People tend to develop inferences based on their own observations and intuition. When facing conflicts between these inferences and real phenomena, they may be reluctant to change or abandon old concepts, and may even generate new misconceptions by twisting the widely accepted concepts [32–34]. The term "misconception" was firstly proposed by Hancock in 1940 to define a concept not consistent with those recognized by scientific communities or experts in the field. It was argued that misconceptions could originate from a deficiency in detailed observations, a lack of support from the facts, and incorrect interpretations [35]. A misconception can also be defined as a misunderstanding of ideas, objects, or events constructed according to someone's past experience [36]. Simply speaking, misconceptions develop in someone's mind in the absence of official instruction [37].

In the context of science education, studies related to misconception are of crucial importance. That is because, as long as conceptual frameworks are formed based on misconceptions, breaking down, removing, or replacing them with widely accepted scientific concepts is very difficult [38]. Misconceptions may exert a negative effect on future science learning as the false information, confusing logic, and nonscientific beliefs that caused the misconceptions would still be influencing a person's mindset and might strengthen the constructs s/he had already built up. For example, the persistence of misconceptions related to fossil fuels into adulthood was verified in a study. The results showed that many preservice teachers did not have enough knowledge about fossil fuels, making their performance on planned interviews and that of elementary school students similar to each other [39].

The task of deleting one mental framework, in other words a "preconception", and replacing it with another is not easy at all [40]. Experiences in the past may not lead to correct outcomes or all possible alternatives [41]. Misleading or misinformation from family members such as parents, the media, and teachers were also important, especially because they held the image of being convincing or authoritarian to young students [41,42]. Other sources that have been mentioned as including misinterpreted information are print and electronic materials, erroneous analogy with known concepts, misunderstanding some symbols, and mixing terms with others with similar but different meanings [39]. Some sources related to personal characteristics and social constructs were also discussed, such as linguistic barriers, intellectual disability, memory confusion, pupil effects, and cultural uniqueness [43–45].

In line with the causes of misconception, types of misconception were also proposed. A relatively classical classification was recommended by the Committee on Undergraduate Science Education of National Research Council in 1997, which encompassed "perceived notation", "nonscientific beliefs", "conceptual misunderstanding", "vernacular misconceptions", and "factual misconceptions". Five themes of misconceptions were proposed by Smith [46]. They were "experience", "self-constructed", "taught-and-learned", "vernacular", and "religious misconceptions". Recently, Yasri [42] reorganized and rearranged these into five categories: "common sense", "vernacular", "non-scientific", "content-based", and "NOS (nature of science)-based" misconceptions, and applied them to biological evolution.

A number of suggestions on how to identify misconceptions have been made by researchers as well as professional societies. A technique combining "peer instruction" and "concept test" was developed by Mazur to help students find their misconceptions and figure out real scientific concepts by themselves [40,47]. As understanding how people learn is the core of overcoming misconception, techniques that can demonstrate the structure of a scientific concept and the path of learning have the potential to dig out and remove misconceptions. "Concept map" is one among these techniques that have been used and proven helpful in some studies [40,48,49]. Interactive tutoring systems have also been developed and applied to misconception identification and alignment [50,51]. Similar to a concept map, a learning path model for clarifying the path of learning a science concept was designed. Misconception identification models were developed based on textual entailment techniques [52], instead of demonstrations.

In addition, more studies related to misconception identification have been carried out with interviews, sometimes mixed with questionnaires. Researchers had conversations with students and preservice teachers for identifying some school-made misconceptions such as the composition of salts, chemical reactions, and the composition of water [53]. Structured interviews were conducted with students from grade 1 to grade 6, and some preservice teachers in an educational college in New York State, USA for understanding their misconceptions regarding the mining, use, and environmental impacts of fossil fuels [39]. Six students were interviewed with a predetermined set of questions to define three scientific concepts and the accompanying misconceptions in a study in Australia [41]. Similar methodologies mainly covering structured or semi-constructed interviews followed by data analysis were also employed in other studies [18,54,55].

General misconceptions about energy have been studied in recent years as energy is such an important and challenging issue and misconceptions and their persistence into the adulthood, as mentioned in the preceding, may make the communication of energy policies difficult. Especially in a democratic and open society, where information is relatively transparent and citizens are empowered to participate in the decision-making process on energy-related policies, misconceptions may result in biased communication, leading to the general public's preference for or objection to specific energy options [56]. Many people in Germany were found to overestimate the contribution of nuclear energy, while underestimating that of fossil fuels and renewable energy sources [16]. A combination of multiple choice and open-ended questions was used to examine high school students' misconception on how solar cells work in California, USA. The students' concepts of the role of light and heat were found to be problematic [19]. Other studies, mainly conducted using questionnaires and interviews, have also reached the conclusion that misconceptions about energy did exist commonly in students and teachers in primary and secondary education [49,57,58]. As mentioned, these may lead to erroneous information, understanding, or interpretation of energy issues and insufficient support for sustainability-oriented energy policies.

In this paper, a set of energy literacy scales was developed, acting as the basis of a questionnaire survey to be conducted with respect to junior high school students in Taiwan. Energy knowledge-related concepts formed the core of this energy literacy survey, making it unique in terms of designated purposes. Their energy literacy was then analyzed to find the scores in the categories of knowledge, attitude, and behavior, together with the correlations among them. These served as the basis for misconception analysis. As mentioned in the preceding, a concept map and a learning path model were used to demonstrate misconceptions. However, a framework for identifying, demonstrating, and classifying misconceptions and at the same time linking the sources and outcomes was not available. Thus, in this study, selected persons were interviewed to find why and how they held these misconceptions. Analytical tools were developed to demonstrate the "conceptual logic map" of a specific person regarding the patterns, the corresponding sources, and developing paths of the misconceptions. Figure 1 showed the framework and processes of this study, in which "development of energy literacy scale", "design of survey questionnaire and result analysis", and "misconception identification and demonstration" are the major phases of the task in sequence. The survey questions in the category of "energy knowledge" were basically designed with consideration of identifying misconceptions and thus, in the final phase, interview questions were designed according to these survey questions together with the survey results.

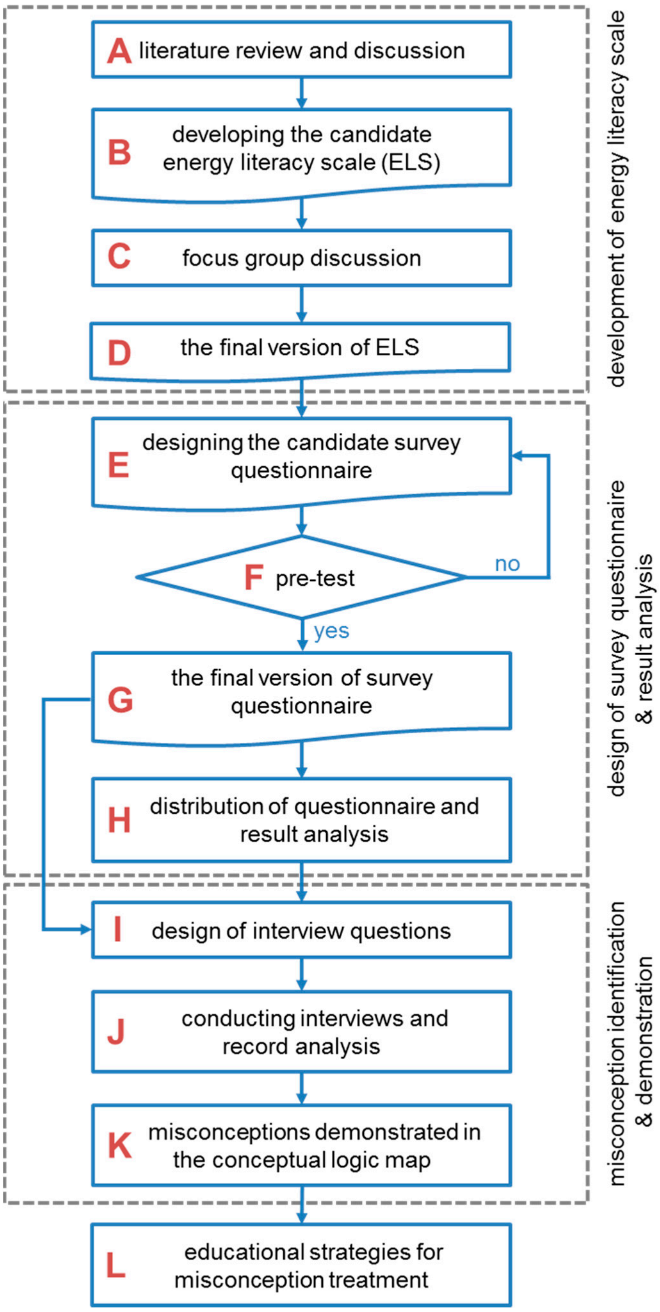

Figure 1. The framework and processes of this study.

3. Methodology

3.1. Development of the Energy Literacy Scales

Energy literacy scales, i.e., an index system with components, sub-components, and indicators, were developed using a focus group approach. Questionnaires were then developed following a relatively comprehensive procedure, in which an ad hoc approach was used for designing a questionnaire with reliability and validity Data collected from the survey were then analyzed using independent samples *t*-test and one-way analysis of variance (ANOVA) to understand the correlation between components and some demographical variables or personal characteristics. Pearson product-moment correlation analysis was then conducted for catching the interrelationships between the components. Ten junior high students were interviewed to understand why and how they held the misconceptions about energy. Misconceptions were identified and classified and then depicted in a "conceptual logic map" for demonstration and further study.

In this research, the energy literacy guidelines published by the Department of Energy, USA were adopted as one of the major references, mainly for the seven principles and some items in the scales. On the other hand, as environment-related literacy scales were established with components for "knowledge", "attitude", and "action", or, in other words, "cognition", "affection", and "behavior", similar structuring ideas were used in this study. "Knowledge", "attitude", and "action and skill" were the three major components. Several sub-components and corresponding indicators were determined by the research team and then discussed through several focus group meetings. Members invited to attend these meetings included professors and scholars in the fields of energy management, environmental engineering, forestry, environmental education, and science education, school teachers, NGO leaders, and government officials. As the energy literacy to be developed would be applicable to students at different learning stages, the invited members were separated into sub-groups for discussion the energy literacy for primary, secondary, and higher education. General discussions followed the sub-group meetings for integrating opinions. The framework and context of the energy literacy were modified to a significant extent during those focus group meetings. Finally, the components were determined as "energy knowledge", "energy and life", and "citizen responsibility and action", in which "energy knowledge" was about cognition, sub-components in "energy and life" were partially about cognition and partially about affection, and indicators in "citizen responsibility and action" belonged to both affective and behavioral aspects. Table 1 summarizes the components together with the definitions, and the sub-components of the final version of the energy literacy developed for this study were suitable to high school students. Under a sub-component, there were several "indicators" that included several "goals". For example, for the indicator #1-1-1: basic knowledge about energy, the three goals included "understand that energy is a physical measure following precise natural laws", "know the classifications, patterns, and characteristics of energy", and "understand the methods and corresponding risks of energy storage".

Table 1. The components and sub-components of the energy literacy scales determined by the focus group meetings.

Component 1: energy knowledge	
Sub-component 1-1: basic concepts about energy Definition: can understand the basic scientific knowledge, rules and theories, and process of energy transfer or transformation	
Indicators	number of goals
1-1-1: basic knowledge about energy	3
1-1-2: basic laws about energy	3
1-1-3: energy transfer and transformation	4
Sub-component 1-2: system concepts about knowledge Definition: can understand the influences of energy flows, and the roles energy plays in ecosystems	
1-2-1: understand the influence of energy flows	5
1-2-2: understand how important energy is for ecosystems	3
Component 2: energy and life	
Sub-component 2-1: development and use of energy Definition: can understand the general situations for the development and depletion of energy, the processes of development and use of energy, and the corresponding environmental impacts	
2-1-1: understand knowledge related to energy consumption and depletion	4
2-1-2: understand the importance of energy development	4
2-1-3: understand the impacts of energy development and use on the environment	3

Table 1. *Cont.*

Sub-component 2-2: decision-making about energy Definition: can understand that the decision-making process about energy contains a series of complex and multi-level assessments based on their knowledge of energy infrastructure	
2-2-1: understand energy infrastructure	3
2-2-2: understand that personal quality of life and society as a whole may be influenced by the selection of energy sources	5
2-2-3: understand that energy-related decision-making processes have multiple levels and are complex	5
Sub-component 2-3: energy issues and worldview Definition: can understand how energy issues influence human life	
2-3-1: understand issues about energy development	4
2-3-2: understand the big issues originating from energy development	7
Component 3: citizen responsibility and action	
Sub-component 3-1: personal awareness and individual actions Definition: understand the impacts of personal awareness and actions upon energy selection on lives, the environment, and the economy; and are willing to take energy-saving actions in their daily lives	
3-1-1: aware of the impacts of personal energy selection on lives, the environment, and the economy	3
3-1-2: carry out energy-saving actions in daily life	4
Sub-component 3-2: citizen participation Definition: understand the impacts of development and use of energy on lives, the environment, and the economy; understand their own responsibility as a global citizen and are willing to take more aggressive energy-saving actions	
3-2-1: participate in decision-making and actions about energy conservation	5
3-2-2: actively encourage others to take useful action towards energy conservation	4
3-2-3: practice green consumption	3

3.2. Development of the Questionnaire and Conducting of Survey

The questionnaire to be distributed the students in this study was designed based on the energy literacy scales shown in Table 1. The draft of the questionnaire contained questions corresponding to most of the "goals" under each of the indicators and some other ones related to the personal information of the subjects. Twenty-six questions for "knowledge", 24 questions for "attitude and action", and 10 questions for personal information were included in this draft. This was then examined individually by 14 experts, including 10 professors in the fields of environmental education, science education, environmental engineering, energy economy, and energy management, as well as four secondary teachers from different counties in Taiwan. Collected opinions were then studied, compared, and judged by a three-person core committee. These steps built up the expert validity or content validity of the questionnaire.

To further ascertain the validity and reliability of the questionnaire, a pre-test was conducted with respect to 297 students from three junior high schools in Taiwan, two in the North and one in the South. The "true" or "false" questions and single-choice questions in the "knowledge" category were analyzed with two indices: degree of difficulty (P) and degree of discrimination (D); the former can indicate whether a question is too difficult or not, whereas the latter measures if one specific question can indicate the student's performance, i.e., belonging to a "higher score" group or a "lower score" one or not. A P value between 0.30 and 0.70 and a D value larger than 0.30 mean "very good". These would be the referential rules for determining if a question would be removed or kept. However, a question can be kept for some special reasons, e.g., as an index of some important concept or term.

Questions in the "attitude and action" categories with a five-point Likert scale underwent other tests including independent samples *t*-test, correlation analysis, and Cronbach's α to confirm the reliability. The critical ratio (CR value) is the *t*-value of the independent samples *t*-test of the mean variances of the highest 27% of scores and the lowest 27% of scores. Correlation analysis was conducted to understand how much the score of one specific question relates to the total score, where the Pearson product-moment correlation is the statistical measure and $p < 0.5$ is still the criterion of significance. Cronbach's α is suitable for these questions with a Likert scale as the indicator of extent of agreement. In general, a Cronbach's $\alpha > 0.7$ means acceptable reliability. The overall Cronbach's α was approximately 0.805, indicating that the reliability is high. Each of the questions was examined according to the results of the *p*-values of the *t*-test and correlation analysis, as well as the Cronbach's α in the absence of that question.

According to the tests and judgements conducted above, the final version of the questionnaire was then ready to distribute to the students. Nineteen questions of "knowledge", 21 questions of "attitude and action", and 10 on personal information were included. Based on the statistics of the Ministry of Education of Taiwan, there were 844,884 enrolled junior high school students. The minimum number of sample with a 95% confidence level and $\pm$5% error can be calculated as 384. With a prediction for the return ratio as 60%, 640 official questionnaires needed to be distributed.

The 19 cities and counties in Taiwan can be categorized into four regions, North, Central, South, East, and Islands. The number of samples in each region was then determined by multiplying the total number of samples (640) by the percentage of enrolled junior high school students of that region. Thus, 283, 154, 169, 30, and four questionnaires were needed in North, Central, South, East, and Islands, respectively. For convenience of sampling, purposive sampling was undertaken and a total number of 1652 questionnaires were distributed, with 615, 349, 394, 164, and 130 in each of the five regions.

3.3. Interviews for Identifying Misconceptions

Important scientific concepts can be found in each of the questions in the "knowledge" category, so while a wrong answer probably means misconceptions held by the respondent, a correct answer cannot guarantee there is no misconception. The 19 survey questions in the category of "energy knowledge" served as the basis for designing the interview questions for identifying misconceptions. Seven of the 19 survey questions had straightforward answers without conceptual elements and thus the interview questions were developed through examining and reorganizing the concepts of the other 12 survey questions. For example, for the survey question "Burning of gasoline is a process of releasing the stored energy of ancient biology", the corresponding interview question can be "How did fossil fuels form? Could you explain where the energy of fossil fuels comes from?" Based on the response of the participants, misconceptions can then be identified and then further analyzed. These interview questions served as the basis of an effective interview, but the interviewer could ask impromptu questions as well. Thus, these will be semi-structured interviews. The interview questions are listed in Table 2.

The participants in the interview were purposively sampled from the respondents of the survey questionnaire. Ten students, nine from the North and one from the South, were invited to participate in the interview. The nine students from the North who answered the survey questionnaire gained fair scores, whereas the student from the South performed well in the survey. The interviewer was a graduate student majoring in Environmental Education and was trained by one professor and two junior high school teachers before he carried out the interview. All of the conversations were recorded upon the participants' agreement for further examination. The 10 students were all 8th graders (the second year in junior high school) and thus the gender and order of interview were recorded as their identity. For example, JHS_G_06 indicates she was the sixth participant interviewed. The interview records were represented as detailed transcripts, with some information not related to the issues of the interview, such as the official explanation before the interview, social conversation, and meaningless redundant words, removed. Detailed content analysis was then conducted for identifying the misconceptions and development paths.

Table 2. The survey questions and corresponding semi-structured interview questions.

Survey Questions	Interview Questions
4. Solar radiation is uniformly distributed on Earth. 10. The major driving force of the weather systems on Earth is geothermal energy.	Do you know the difference between weather and climate? What causes the current status of the weather and climate?
13. The calories in rice were transferred from the sunlight via photosynthesis.	What do you think the importance of the Sun is for Earth, human beings, and other living things? How do living organisms utilize the energy from the sun?
11. The GHG gases in the atmosphere catch the solar radiation from outer space and bring about the Greenhouse Effect. 12. As long as human beings stop emitting GHG gases, climate change and global warming will be mitigated right away.	Can you explain what causes the Greenhouse Effect? Can you give the names of two GHG gases? Where did you get this information?
5. Coal, petroleum, and natural gas are called "petroleum–chemical fuels".	Have you ever heard of "fossil fuels"? Where did you hear about them? Please explain the meaning of fossil fuels. Can you identify the differences between "petroleum–chemical fuels" and "fossil fuels"?
6. Burning of gasoline is a process of releasing the stored energy of ancient biology.	How did fossil fuels form? Could you explain where the energy of fossil fuels comes from?
16. The high-level nuclear waste of Taiwan is stored on Lanyu Island.	Do you know how a nuclear power plant generates electricity? Have you heard of high-level and low-level nuclear waste? From where did you learn about them? Also explain the differences between them.
14. Taiwan is abundant in energy sources that supply over one-half of the domestic demand.	Do you think energy sources in Taiwan are adequate? What are the major sources of the energy used in Taiwan? How did you know this?
2. Which of the following numbers is closest to the percentage of renewable energy in Taiwan?	Which among thermal power, nuclear power, and renewables is the major source of electricity? Whose cost is the highest?
3. The electricity consumption of some industrial park is 50,000 kW. Is this a correct statement?	Have you heard of "kW", "kW-hr", "degree of electricity" [1]? What are the differences among them?
19. Biofuel made of corn is a kind of clean fuel developed and recommended by countries around the world.	How do you think corn-made biofuel can help the future world? Any drawbacks? How do you know this information?

Notes: [1] In Taiwan, "one degree of electricity" is the common term of "kW-hr".

The reliability was confirmed through a series of tasks. Approval of recording was offered by the participants to ensure the quality of the first-hand data collected. To avoid over-inference, content analysis should be based on raw words instead of the analyzer's interpretation. The analyzer needed to remind himself/herself to eliminate potential discrepancies. Two analyzers, one the interviewer and the other a graduate student familiar with energy and climate issues, worked on each of the transcripts in parallel, with the scores from their rating tasks compared. The reliability was calculated to be as high as 0.90.

Efforts were also made to enhance the validity as much as possible. The transcripts were coded and classified to ensure the correctness and integrity of the data collected. Triangulation techniques were also employed, in which the triangulation of approaches was realized by data collected via both paper-and-pen tests and qualitative interviews; the triangulation of data sources was endorsed through a comparison and check of data collected from survey questionnaires and interviews.

4. Results of the Energy Literacy Survey

4.1. Sample Description

A total of 1652 questionnaires were distributed to junior high schools in five regions of Taiwan in October and November 2013. A total of 1231 effective samples were collected, resulting in an effective response rate of 75.4%. Among them, there were 608 boys and 623 girls, equivalent to 49.4% and 50.6%, respectively. In Taiwan, there are three grades in junior high schools, corresponding to grades 7 through 9 in Western countries. The percentages of effective samples for grades 7, 8, and 9 were 32.3%, 34.0%, and 33.9%, respectively. These indicated that the samples were relatively homogeneous in terms of gender and grade.

As for regional distribution, there were 324, 305, 382, 140, and 80 samples in North, Central, South, East, and the Islands, respectively. In addition, the highest educational level (HEL) and occupation of the student respondent's parents were also included as personal information. The top three HELs of the students' parents were high school (36.2%), college (21.2%), and junior college (17.0%). The top five occupations of the students' fathers' occupation were laborer (26.8%), service (20.1%), commerce (19.9%), others (11.0%), and government official (10.0%); whereas those of the student's mothers' occupation were service (30.6%), others (27.0%), commerce (18.2%), laborer (9.2%), and government official (6.7%). "Transportation of commuting" and "information source of energy" were two items asked using multiple choice questions. For "transportation of commuting", "walk" (47.9), "motorcycle pick-up" (34.0%), "car pick-up" (29.1%), "bike" (24.5%), and "bus" (14.0%) were options chosen by more than 10% of the students. Table 3 lists the numbers and percentages of students who picked the option "information source of energy". Most students know about energy from TV; many students got information about energy from Internet and school courses.

Table 3. Numbers and percentages of students selecting options of "information source of energy".

Information Source	Yes	No
School course	854 69.4%	377 30.6%
Books	572 46.5%	659 53.5%
TV	995 80.8%	236 19.2%
Internet	893 72.5%	338 27.5%
Newspapers/magazines	526 42.7%	705 57.3%
Other	45 3.7%	1186 96.3%

4.2. Energy-Related Knowledge

The questionnaires included three components, seven sub-components, and 18 indicators, in which two components, five sub-components, and 11 indicators, corresponding to 19 questions, belonged to the category of "knowledge". A correct answer would be counted as one score and thus the full score would be 19. The resulting scores ranged from 3 to 17, in which a score of 8 to 13 was gained by most students. The average score of the students was 10.1, equivalent to 53.2 if calculated as a percentage. This indicated that the students did not perform well in "knowledge". Among the 11 indicators, "understand the importance of energy in the ecosystems" was the one with the most correct answers (81.6%). On the other hand, the indicators with the lowest scores were "energy transfer and transformation" (31.2%) and "understand the impacts of energy development and use on the environment" (32.8%).

Among the 19 questions, seven were answered correctly by more than 60% of the students whereas seven were answered correctly by less than 40%. In general, the students were more familiar with topics taught at school, e.g., knowledge and theories of ecology, climate change, and energy infrastructure. However, they did not know much about in-depth scientific issues such as the principles of the Greenhouse Effect and nuclear power generation, as well as the overall energy status in Taiwan and internationally. The seven questions with the lowest rates of correctness can be found in Table 4. The smallest number of students correctly answered the question "Are coal, petroleum, and natural gas collectively called 'petroleum–chemical fuels'?". In Chinese, the characters for "fossil" are 化石, whereas those for "petroleum–chemical" are 石化. Many people got confused about these terms and tended to call "fossil fuels" "petroleum–chemical fuels". This made many think that only petroleum can cause anthropogenic carbon emissions, but coal and natural gas will not.

Table 4. The seven questions with the fewest students answering correctly in the "knowledge" category.

Question	The Percentage of Correct Answers
5. Coal, petroleum, and natural gas are collectively called "petroleum–chemical fuels".	16.7%
2. The share of electricity generated by solar energy sources is closest to (1) 5% (2) 10% (3) 35%, or (4) 60%.	26.2%
7. LPG stored in steel tanks is gas with high pressure that can be released to be used by customers.	27.6%
19. Biofuel made of corn is a kind of clean fuel developed and recommended by countries around the world.	33.7%
16. The high-level nuclear waste of Taiwan is stored on Lanyu Island.	34.8%
9. The efficiency of the PV modules sold in public markets is as high as 40%.	36.5%
1. Which of the following is NOT a major petroleum output country? (1) Saudi Arabia (2) Russia (3) Germany, or (4) Mexico.	40.0%

To understand if differences in the performance on "knowledge" can be identified with respect to different backgrounds, the independent samples *t*-test was employed to examine the correlations between the knowledge scores and the background-related variables, i.e., gender, grade, region, school attributes (public or private), HEL of parents, occupation of father, and occupation of mother. It was found that male students scored significantly better than female students ($p < 0.01$) in energy knowledge. If analyzed by the indicators, male students' scores for "the basic laws about energy", "energy transfer and transformation", and "understand the impacts of energy flows" are significantly better than the scores of female students, with the latter two most significant ($p < 0.001$).

For those variables such as "grade" with more than two sets, more statistical tests need to be conducted to find the significance of difference among the different sets. Levene's test was used first to check the homogeneity of variance among the sets. If the tests were passed ($p < 0.05$), the scores of the sets would be analyzed via ANOVA to check the F value and significance, followed by post hoc analysis or multiple comparison using the Scheffe Method. On the other hand, if the variances among sets were found to be nonhomogeneous, Robust Tests of Equality of Means would be employed for testing the significance, followed by Games–Howell post hoc analysis. Following these rules, very high significance was obtained among the three grades ($p < 0.001$). The 8th graders and 9th graders both scored significantly better than the 7th graders. Similar results can be found with respect to seven out of the 11 indicators in the "knowledge" category. This indicated that they could have experienced a significant promotion in energy knowledge when they upgraded from the 7th to the 8th grade.

For students in different regions, following the same rules, it was confirmed that students in North, Central, South, and East Taiwan scored significantly better than those in the Islands area ($p < 0.001$). In Taiwan, people living in the remote islands (Penghu, Kinmen, and Machu) have relatively limited access to a well-established learning environment. In addition, they have their own independent energy system relying almost 100% on fossil fuels. This may make residents, including students, think less about energy.

HEL and the occupation of the parents were also found to be variables with significant differences among the sets. Students with their parents with HEL as "Ph.D./master", or "college/junior college" scored significantly better than those who had graduated from senior or junior high schools ($p < 0.001$).

The impact of parents' educational level on the students' energy knowledge is obvious, indicating that family education plays a key role in students' understanding of energy issues. Students with a father or mother working as an educator scored significantly better than those with parents in other professions ($p < 0.001$). It seems that parents working in the educational field tend to offer a better learning environment to their children. This is consistent with the conclusion regarding the importance of family education shown above. The statistics for analysis of education of parents are included in Table 5. For other background-related variables, no significance in scores was identified among sets.

Table 5. The analysis of knowledge scores of students with different parents' HELs.

Education	Sample Size	Mean/% Score	*F* Value	Significance (*p*)	Post-Hoc Analysis (Scheffe)
Ph.D./master	152	11.15/58.7	23.33	*** 0.000	Ph.D./master > Senior and junior high school College/junior college > Senior and junior high school
College/junior college	470	10.53/55.4			
Senior and junior high school	545	9.47/49.8			
Elementary school and below	9	9.78/51.5			
Other	55	9.35/49.2			
Total score	1231	10.1/53.2			

Notes: *** $p < 0.001$.

4.3. Energy-Related Attitudes and Actions

Two components, "energy and life" and "citizen responsibility and action", five sub-components, and 10 indicators, corresponding to 24 questions, belonged to the category of "attitude and action". These questions were designed to measure the degrees of agreement for a statement or an action, corresponding to attitude or behavioral intention. The questions in this category were scored using a five-point Likert scale. A score of 5, 4, 3, 2, and 1 was assigned to the answers "strongly agree", "agree", "neutral opinion", "do not agree", and "do not agree at all", respectively. The average score of these questions was 3.60 (out of 5.00) and the standard deviation was 2.36, with the highest average score for "I understand that personal quality of life and society may be impacted by my selection of energy" (3.96) and the lowest score for "I understand the importance of energy development" (2.08). According to these scores, it can be stated that students have an active attitude toward energy.

Through looking at the answers to each of the questions, we could understand how the students thought about energy issues. The students thought that a scarcity of fossil fuels may exert noteworthy impacts on the economy and human life, and the use of fossil fuels resulted in climate change. They tended to agree that renewable energy needed to be developed regardless of the relatively higher costs. At the same time, technological progress needed to accelerate to reduce costs and promote the competitiveness of renewable energy sources. Over 60% of students agreed that wind turbines should be widespread to generate electricity, replacing thermal electricity. Yet, they seemed not to understand much about the geographical and social limitations of inland and coastal wind turbine projects in Taiwan. This can be clarified through interviews. Collectively, the students had a positive attitude about the development of renewable energy sources.

It was also observed from Question A4 that most students came to an understanding that we should keep gasoline for industrial uses inexpensive to maintain industries' international competitiveness. Only 16.2% of them thought we need to raise prices. The students had a relatively conservative attitude toward utilities pricing, although subsidies on fossil fuels have already become one of the key issues in GHG emission control and management in Taiwan as over 98% of the primary energy sources are imported and approximately 90% of carbon emissions are related to fossil fuel energy use [59]. Question A9 was designed to understand students' tendency for selecting between "development paradigm" and "conservation paradigm" when facing the challenge of electricity shortage. Results showed that they tended to take a neutral position upon this issue (41.4%).

It was also indicated that the students had a strong intention to take personal environmentally friendly actions, e.g., reducing air conditioning use, taking public transportation as often as possible, and bringing personal eating utensils. However, 37.2% of students chose to stay neutral when asked to sacrifice their convenience for energy conservation, although over 50% said yes. This revealed the fact that "sacrifice framing" is not attractive to people, whereas "motivational framing" is more convincing, as discussed by Gifford and Comeau [60]. Moreover, students were active in encouraging their families and pupils to carry out energy conservation, yet at the same time thought it is not easy to persuade others to be environmentally friendly. Table 6 summarizes the score distributions of some of the questions mentioned.

Table 6. Selected questions and the score distributions in "attitude and action" category.

Question	Percentage (%) [1]				
	Agree +	**Agree**	**Neutral**	**Do Not Agree**	**Do Not Agree −**
A2. Renewable energy sources need to be developed, although they are relatively expensive.	27.7	*32.2*	31.7	6.5	1.8
A4. For attracting more investment from outside and facilitating economic growth, the price of gasoline used by industries should not increase.	20.8	18.3	*44.6*	11.4	4.8
A9. I think the best way to solve the problem of electricity shortage is building more power plants.	11.1	26.1	*41.4*	12.9	8.4
A11. I am willing to reduce my use of air conditioning for energy conservation.	*37.2*	32.2	24.2	4.1	2.1
A12. I am willing to take public transportation to reduce carbon emissions and combat climate change.	*44.2*	32.8	19.8	2.6	0.4
A14. I am willing to tolerate the inconveniences brought about by energy conservation.	20.9	30.5	*37.4*	7.2	3.8

Notes: [1] "Agree +" means "strongly agree"; "Do Not Agree −" means "do not agree at all".

Similar statistical testing approaches can be used to examine whether any of the background variables may have a significant influence on the students' attitude and behavioral intention. It was, surprisingly, found that no significance could be identified for most of the background information. The 8th graders had a significantly more active attitude and behavioral intention than the 9th graders. This indicated a declining intention to take energy conservation-related action among junior high school students. For other background variables including gender, region, school attribute, parents' HEL, father's occupation, and mother's occupation, no significant difference in attitude and behavioral intention could be found in general, although some can identified for a few specific questions. These results may indicate that their affective and behavioral constructs were already built up by their living and learning experiences, which were basically homogeneous in the territory of Taiwan, when they were younger.

4.4. Correlations among Components and Sub-Components

It needs to be stated again that questions in the "knowledge" category of the questionnaire were designed corresponding to the component "energy knowledge" (EK) and some sub-components of the component "energy and life" (EL) of the energy literacy scales developed; questions in the "attitude and action" category were designed to correspond to the component "citizen responsibility and action" (CRA) and some sub-components of the component "energy and life". Pearson product-moment correlation was employed to determine the correlations among the components and sub-components of the energy literacy scales. Table 7 illustrates the correlations among the components EK, EL, and CRA. Significant correlations were found between EK and EL (r = 0.171), as well as EL and CRA (r = 0.166). However, as the correlation coefficients were small, the explanatory abilities were relatively low. There was no significant correlation between EK and CRA, showing that the scores for energy knowledge did not have a significant impact on students' citizen responsibility and action. A correlation analysis was also carried out for the subcomponents of EK and EL. Each of the three sub-components of EL was divided into two categories, "knowledge" and "attitude and action". There are two subcomponents for EK. The component itself can be treated as a comprehensive sub-component. Thus, these produce a total of $(3 \times 2 + 1) \times (2 + 1) = 21$ correlations to be checked. Among these, 13 correlations with high significance ($p < 0.01$) and one correlation with medium significance ($p < 0.05$) were identified. In general, correlations among the "knowledge"-related subcomponents were relatively higher than those among "knowledge"-related subcomponents and "attitude and action"-related ones. Nevertheless, the explanatory abilities were all not high, with r between 0.088 and 0.224.

Table 7. Correlations among the components of the energy literacy scales.

Component		Component 1: Energy Knowledge	Component 2: Energy and Life	Component 3: Citizen Responsibility and Action
Component 1: energy knowledge	Pearson r	/	**0.171 ****	−0.036
	significance	/	**0.000**	0.204
Component 2: energy and life	Pearson r	**0.171 ****	/	**0.166 ****
	significance	**0.000**	/	**0.000**
Component 3: citizen responsibility and action	Pearson r	−0.036	**0.166 ****	/
	significance	0.204	**0.000**	/

Notes: ** $p < 0.01$

There are two subcomponents for CRA. Thus, based on the same analysis, there would be also 21 correlations to be checked between EL and CRA. The results are listed in Table A1 in Appendix A, in which some correlations with high significance ($p < 0.01$) and low–medium explanatory abilities can be found. It can be observed that subcomponent 2-2(AC), decision-making about energy in the "attitude and action" category, may have a positive effect on "citizen responsibility and action" (CRA). Complex evaluations are needed for decision-making about energy as they may have an extensive impact on the economy, environment, and society; students with a relatively positive attitude and behavioral intention can understand how their choices could influence the whole of society and hence are willing to take more drastic action accordingly.

5. Results of the Interview

5.1. Implementation of the Interview

It was observed from the survey that the students tend to score worse with respect to those questions related to some specific misconceptions, regardless of their total scores in knowledge. Thus, questions for interviews were designed corresponding to several survey questions, as shown in Table 2. Ten students were selected to be the participants. Among them, nine students from North Taiwan made similar mistakes in the survey and the tenth student was a female student from the South who scored relatively better than the average. In total, there were three male students and seven female students participating in this interview, coded as JHS_G_N, in which JHS means junior high school, G is the code for gender (B for a male and G for a female), and N is the order. Table 8 listed the distribution of correct answers in the corresponding survey questions of the 10 interviewed students, where 1 or 0 represented a correct or incorrect answer, respectively. For each of the survey questions, the accuracy rate of the 10 interviewed students was also compared with that of the whole group. The correlation coefficient was as high as 0.63, indicating a good degree of consistency between the interviewed students and the whole group. The total number of correct answers of the 10 interviewed students was distributed smoothly from three to 10, representing the diversity of the 10 interviewed students.

Table 8. Distribution of answers to the corresponding survey questions of the 10 interviewed students.

Question #	# of the Interviewed Student [1]										Mean [2]	μ [3]
	1	2	3	4	5	6	7	8	9	10		
4	1	1	1	0	0	1	1	0	1	1	0.700	0.604
10	1	1	1	0	1	1	0	1	0	1	0.700	0.569
13	1	1	0	1	1	1	0	1	0	1	0.700	0.695
11	0	0	0	0	1	0	0	1	0	0	0.200	0.429
12	1	1	0	1	0	0	0	1	1	1	0.600	0.774
5	0	0	0	0	1	1	0	0	0	1	0.300	0.167
6	0	1	1	1	0	1	1	0	0	1	0.600	0.646
16	1	1	0	1	0	0	1	1	1	0	0.600	0.348
14	1	1	1	0	1	1	0	1	0	1	0.700	0.643
2	0	1	1	0	0	1	0	0	0	1	0.400	0.262
19	0	1	1	0	0	0	0	0	1	1	0.400	0.337
3	0	1	0	0	0	0	0	1	1	0	0.300	0.570
Total Score	**6**	**10**	**6**	**4**	**5**	**7**	**3**	**7**	**5**	**9**		

Notes: [1] 1 indicates a correct answer; 0 indicates an incorrect answer; [2] mean: the average score of the ten interviewed students; [3] μ: the average score of the whole group of 1231 students.

As mentioned in the literature review, there have been different kinds of classifications of misconceptions. In this research, the classification proposed by Shan [61] was adopted as the reference of the interview as well as the following analysis of the logic, which were "intuitive judgement" (Pattern A), "lack of knowledge" (Pattern B), "mistakes from experiences of daily lives" (Pattern C), "misleading from teaching" (Patter D), "logical fallacy" (Pattern E), and "vernacular error" (Pattern F). "Intuitive judgement" means the students judge the meanings or theories of things based on their "feeling" or "intuition" instead of scientific knowledge or understanding. "Lack of knowledge" means the students did not have enough scientific knowledge and hence explained scientific phenomena through guessing. "Mistakes from experiences in daily life" means the students take the information gained from books, the media, the Internet, or their daily lives as real scientific knowledge. "Misleading from teaching" means the students "learn" misconceptions at school because of incorrect information given by teachers, published in textbooks, or in materials in other learning activities. "Logical fallacy" means the students link, combine, or integrate related concepts learned in the past and infer scientific phenomena according to similar ideas or rules. "Intuitive judgement" means the students explain the scientific terms based on the literal meanings of other terms, especially those with the same or similar wording.

The survey questions and corresponding interview questions listed in Table 2 can be summarized as six major "issues" that can be linked to other misconceptions and potential sources and reasons. They were "The Earth's atmospheric system is driven by solar energy", "the impacts of solar energy on biological systems", "the Greenhouse Effect and climate change", "fossil fuels", "energy-related issues", and "energy transfer and transformation". Data collected from the interviews were then analyzed.

For each of the "issues", the percentage of correct answers of each of the related survey questions was firstly calculated. Related dialogue contents of corresponding interview questions were recoded and analyzed for each participant. Once the analyzer found any of the six misconception patterns, s/he marked/coded the patterns in the texts. After integrating all of the coded records, the misconceptions related to that issue can then be illustrated in a conceptual logic map. This is called "issue-oriented misconception analysis". In addition, for each of the participants, if s/he did not reply to one interview question correctly, a diagnosis such as failure to understand some scientific theory or draw some scientific inference could be made. That diagnosis could be linked to the dialogue recorded during the interview as a real example of a misconception, which can then be marked with one or more misconception patterns. This can be named "participant-oriented misconception analysis".

5.2. Issue-Oriented Misconception Analysis

Taking the issue "The Earth's atmospheric system is driven by solar energy" as an example, the two survey questions related to this issue were firstly listed with percentages of incorrect answers as in Table 9. Approximately 40% of the students did not correctly answer the survey questions. Thus, the participants were asked the corresponding interview questions as listed in Table 2. The following are selected records of some of the participants:

Participant JHS_B_01

Q: Have you ever heard of the two terms "weather" and "climate"?
A: Yes.
Q: Could you explain these two terms?
A: Weather is like . . . the weather is getting cold. Climate is a longer concept.
Q: What do you mean by "a longer concept"?
A: A concept for a longer period of time.
Q: How does the weather happen?
A: I don't know (B).
Q: Where did you hear about weather?
A: News and TV.

Participant JHS_B_03

Q: Have you ever heard of the two terms "weather" and "climate"?
A: Yes.
Q: Could you explain these two terms or give me some examples?
A: Weather . . . like the sun shines. Climate . . . "temperature"? (B)
Q: Are they the same thing? Why?
A: No, . . . I don't know. (B)
Q: Where did you hear about them?
A: School (D) *and TV* (C)
Q: So you know they are different but don't know why?
A: Yes.
Q: Then, do you know why there are weather and climate?
A: I don't know. (B)

Table 9. The two survey questions related to "The Earth's atmospheric system is driven by solar energy" and the corresponding percentages of incorrect answers.

Question	The Percentage of Incorrect Answers
4. Energy of solar radiation is uniformly distributed on Earth	39.6%
10. The major driving force of the weather systems on the Earth's surface is geothermal energy.	43.1%

With the records of all of the 10 participants, the corresponding misconception patterns could then be examined as follows:

(1) Intuitional judgement (Pattern A)
Because of a lack of knowledge and being familiar with these two terms as they are shown in school classes, the news, or on TV, the students tended to judge weather and climate intuitively. Some students could not explain the climate and weather but concluded they are different.

(2) Lack of knowledge (Pattern B)
It was common that the students did not have enough knowledge regarding weather and climate. Only a few students could state clearly that the time scales are different. Most students could not answer the questions correctly. Some thought the weather is about seasons while climate is about temperature, humidity, and rainfall; or thought that geothermal energy will influence weather and climate.

(3) Mistakes from experiences in daily lives (Pattern C)
As the students said, weather and climate are terms commonly heard in daily life, including in the news and on TV. However, they are not explained clearly and thus students did not identify the differences or have in-depth understanding. This makes the students confused.

(4) Misleading teaching (Pattern D)
Concepts of weather and climate were taught in school classes. However, if they were not explained clearly in teaching or inappropriate examples were mentioned, the students tended to learn incorrect knowledge.

The analysis carried out can then be illustrated in the conceptual logic map of the misconceptions about this issue (Figure 2). The concepts classified by the researcher, those held by the students, and misconception patterns were linked to show the whole picture regarding what the misconceptions are and how they were categorized and linked to other concepts.

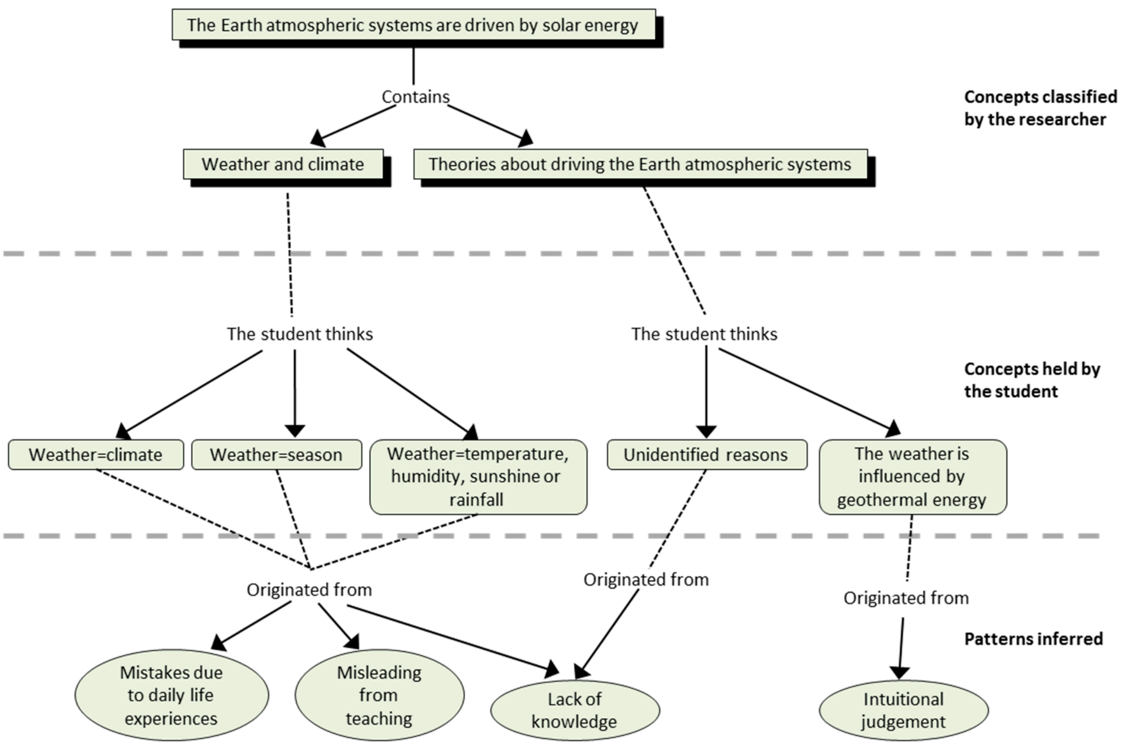

Figure 2. The conceptual logic map of the misconceptions related to "The Earth's atmospheric system is driven by solar energy".

Taking another issue, "fossil fuels", as an example, more misconceptions could be identified. Table 10 lists the two survey questions. It was indicated that more than 80% of the students did not answer the 5th knowledge question of the survey questionnaire. That is, they could not identify the difference between "fossil fuels" and "petroleum–chemical fuels".

Table 10. The two survey questions related to "fossil fuels" and corresponding percentages of incorrect answers.

Question	The Percentage of Incorrect Answers
5. Coal, petroleum, and natural gas are together called "petroleum–chemical fuels".	83.3%
6. Burning petroleum is a process of releasing the energy stored in the debris of ancient organisms.	35.4%

The record of one participant with many misconceptions was also shown in the following:

Participant JHS_G_07

Q: Have you ever heard of the term "petroleum–chemical fuels"?
A: Yes.
Q: What are they?
A: Should be those things like gasoline. (F)
Q: Have you ever heard of the term "fossil fuels"?
A: No. (B)
Q: Then, do you think "fossil fuels" and "petroleum–chemical fuels" are the same?
A: No. (A).
Q: Where did you hear about the term(s)?
A: "Nature" class at school. (D)
Q: Where did you read about the term(s)?
A: Textbooks of biology. (D)
Q: You just mentioned gasoline. How was it formed?
A: Just like things like coal . . . but I did not know how it was formed. (B)
Q: Then, where did gasoline energy come from?
A: Geothermal energy. (B)
Q: So, geothermal energy supplied coal or petroleum energy so that we can use the energy now?
A: Yes!

With the records of all 10 participants, the corresponding misconception patterns could then be examined. All six patterns can be inferred for fossil fuels as many misconceptions could be identified in the dialogues. The conceptual logic map can then be illustrated as in Figure 3.

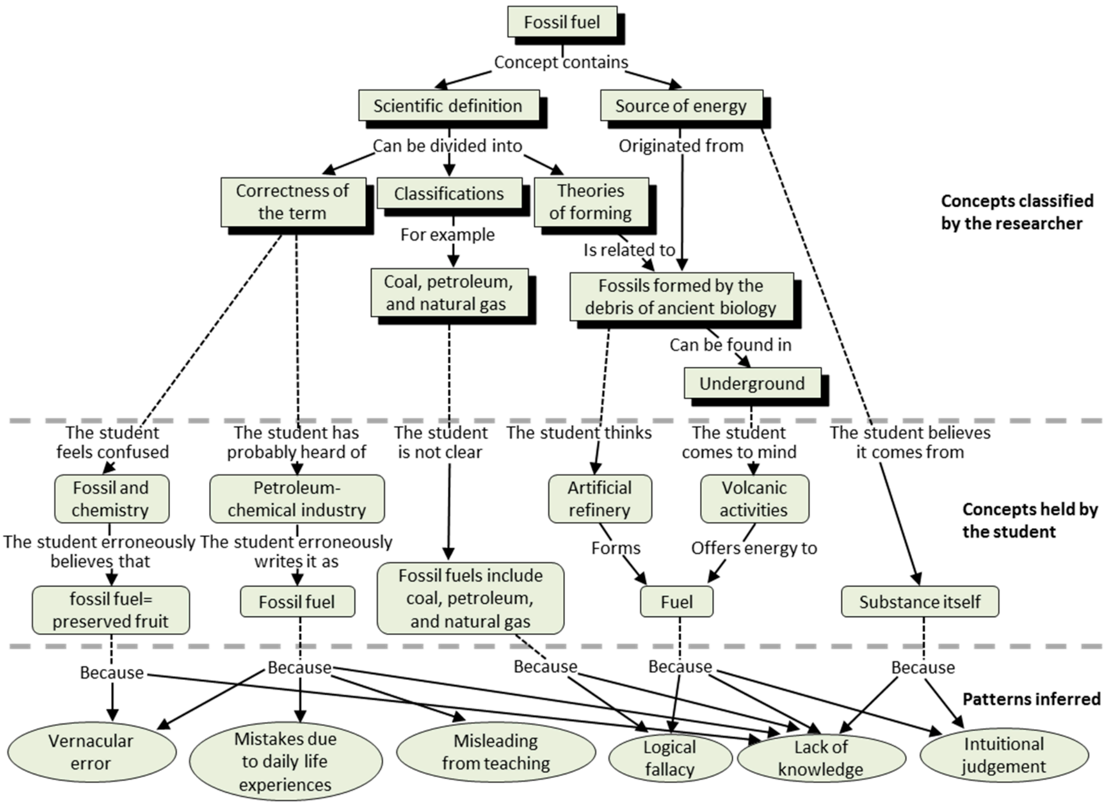

Figure 3. The conceptual logic map of the misconceptions related to "fossil fuels".

5.3. Participant-Oriented Misconception Analysis

By integrating all records of the interviews of the 10 participants, the relationships among the diagnosis of scientific understanding, real examples of misconception, and misconception patterns inferred can be listed and linked. Figure A1 in Appendix A illustrates all of the diagnoses, examples, and patterns that were extracted from the data collected. This can be employed as the reference for misconception analysis of a specific participant.

The following is an example of participant-oriented misconception analysis for JHS_B_01, who was a male student with an outgoing personality. He was able to implement things but not interested in learning and studying. He was in the lower tier of the class. He correctly answered eight out of the 19 questions, resulting in a percentage score of 42.1, lower than the average score of 54.2. He could not clearly explain the meanings of weather and climate but know their difference in time scales. He thought the Sun is important to the Earth only because it offers light for photosynthesis for generating oxygen. Without oxygen, green plants will die. He also thought that the energy of plants comes from the nutrients in the soil. He had heard of "the Greenhouse Effect" and thought this was due to exhaust emissions of industries and motor vehicles in which carbon dioxide led to a temperature rise and icebergs melting. "Climate change" for him meant the changing weather. He thought "petroleum–chemical fuels" meant petroleum and coal, which were dug up from the ground and then refined. He also thought the energy of fossil fuels comes from the substance themselves. He had heard of "fossil fuels" but did not know exactly what this term means. TV was his major information source. He had heard of nuclear power generation from TV news and family members yet did not understand how nuclear electricity was generated. He had heard of nuclear waste and nuclear waste storage but did not know the difference between high- and low-level nuclear waste. He knew some case studies of corn-made fuels but did not know the meaning of bioenergy. He did not know the meanings of kW, kW-hr, and "degree of electricity", although he had seen the term "degree of electricity" on the electricity bill. He could only judge, from his daily life experiences, that it is something related to an electricity bill.

Figure 4 was illustrated as the conceptual logic map of his energy misconceptions for JHS_B_01. It indicated that he held all of the six patterns of misconception. For another female student, the participant-oriented conceptual logic map is shown in Figure 5. A comparison between these two figures manifested the differences in diagnosis of scientific understanding, real examples of misconception, and misconception patterns inferred of the two students. JHS_G_09 had different kinds of misconceptions but similar numbers of scientific misunderstandings and real examples of misconception. However, patterns of "logical fallacy" and "vernacular error" were not found. It seemed that she had better logical capacity and linguistic proficiency. Moreover, it was also found that not every student held many misconceptions regarding energy. JHS_G_10, a female student in the South with an excellent learning performance, answered almost all of the interview questions correctly.

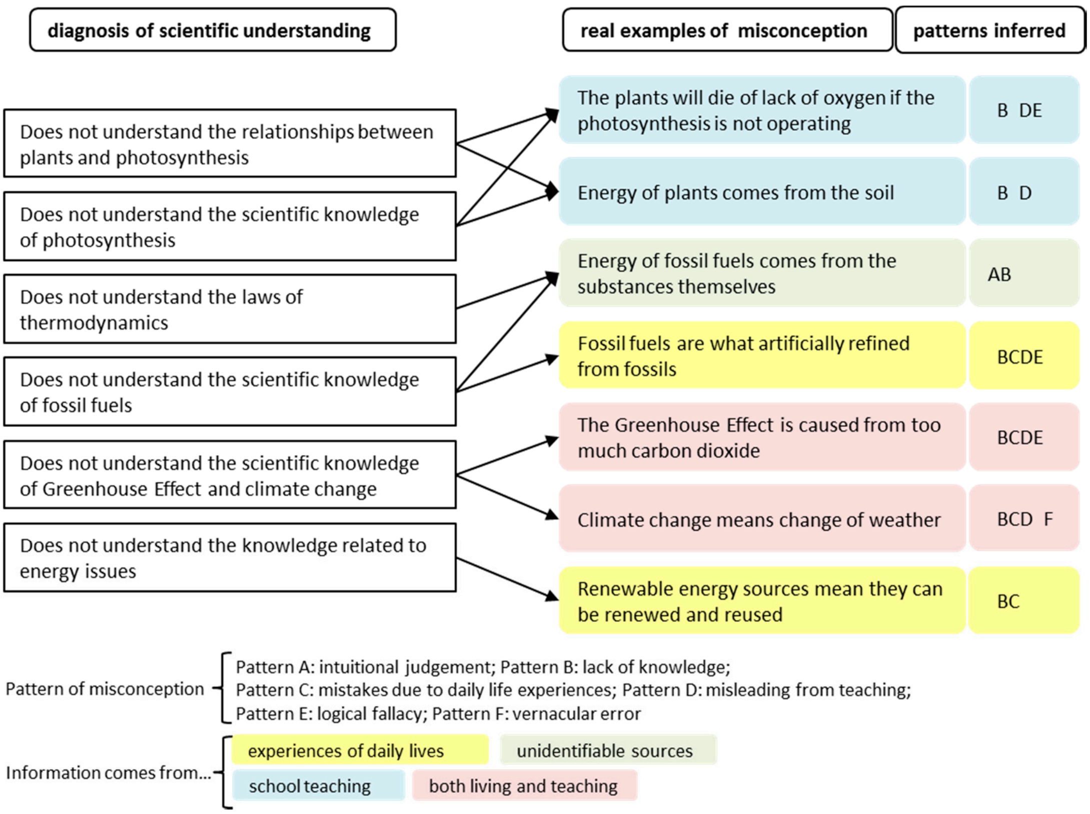

Figure 4. The conceptual logic map of the energy misconceptions for JHS_B_01.

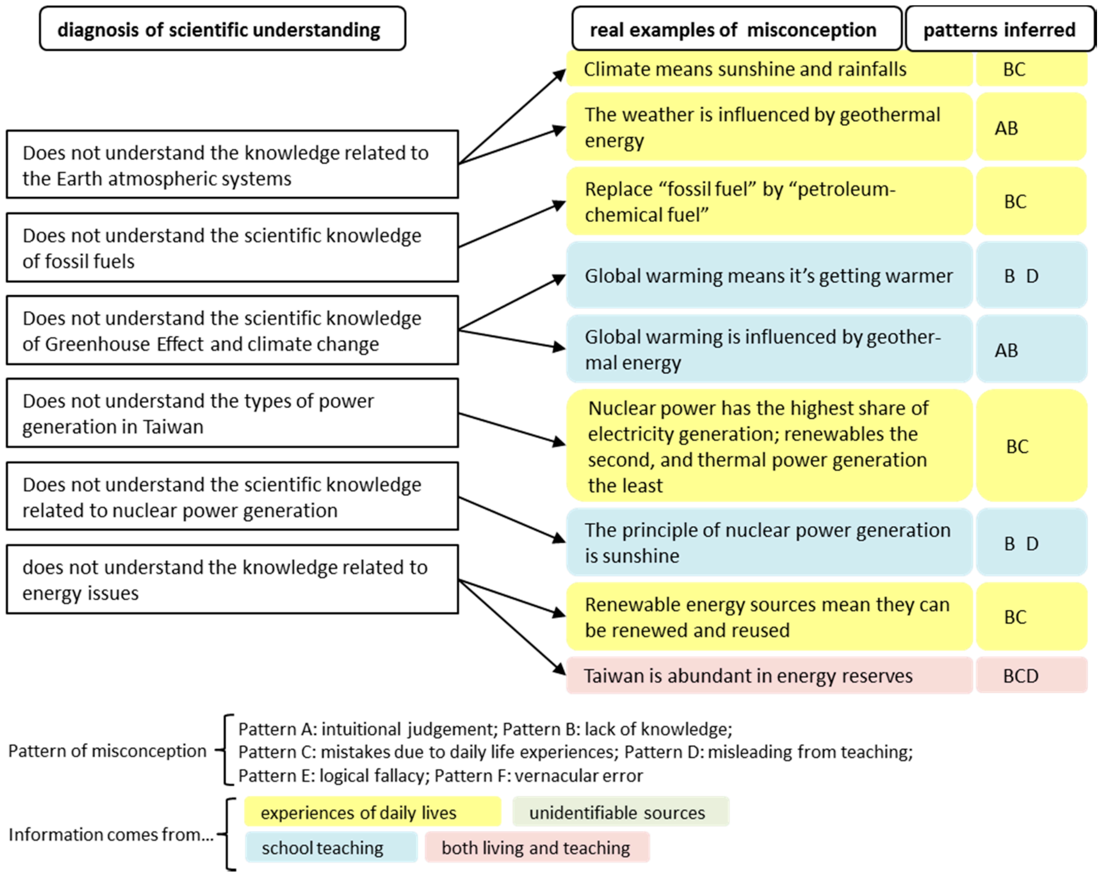

Figure 5. The conceptual logic map of the energy misconceptions for JHS_G_09.

5.4. Potential Educational Strategies to Treat Misconceptions

According to the analysis presented in the preceding, it can be understood that for a student misinformation comes from a variety of sources. In Figures 4 and 5, different patterns of misconception are caused by different reasons. Thus, further analysis can be conducted to find possible "treatment" strategies for different misconceptions. As mentioned in the literature, these treatment strategies may range from pedagogical modification or reform, focused science education to other communication, and environment-related ones such as new media exposure [45,46,59,60].

Based on the pattern of misconceptions, deficiencies, or problems as observed in the survey and interviews, corresponding potential treatment strategies were proposed, as listed in Table 11. In general, a lack of systemthinking, critical thinking, and familiarity with scientific approaches are the fundamental symptoms, showing the basic problems in science education. In terms of learning, a lack of access to learning materials of good quality, low learning achievement, and instructors' inability to teach are among the major concerns. Moreover, misinformation in daily life and the media, together with a lack of linguistic sensitivity and media literacy, made people unable to judge the correctness of information. Treatment strategies for bringing people's misconceptions into line with real scientific concepts included strengthened basic training in logic, systemand critical thinking, and scientific approaches. Improvements in pedagogy, teaching materials, and learning environment are also important. The importance of "train the trainers" (T2) or even "train the trainers' trainers" (T3) needed to be emphasized as the interviewed students mentioned many times that some misconceptions were taught by their schoolteachers. In addition, the quality of media needs to be improved to avoid misinformation or "fake scientific information". The media literacy of the public and students is also essential for them to determine whether media representations can be trusted.

Table 11. Potential treatment strategies for different patterns of misconception.

Pattern of Misconception	Deficiency/Problem	Potential Treatment Strategies
intuitive judgement	■ Lack of systemthinking ■ Lack of critical thinking ■ Unfamiliar with scientific approaches	■ Training in systemthinking and critical thinking ■ Strengthen scientific approaches and practice ■ Promote media literacy
lack of knowledge	■ Lack of access to learning materials ■ Low learning achievements	■ Offer more learning materials and access ■ Modified pedagogies or teaching strategies
mistakes from experience	■ Lack of critical thinking ■ Misinformation in daily life and the media	■ Training in critical thinking ■ Promote science and media literacy ■ Change living and learning environments
misleading from teaching	■ Misinformation in textbooks or other learning materials ■ Instructors' lack of knowledge or misunderstanding	■ Change or modify textbooks ■ Choose learning materials of better quality ■ Train the trainers (of trainers)
logical fallacy	■ Lack of logic training ■ Lack of systemthinking ■ Lack of critical thinking	■ Training in logic ■ Training in systemthinking and critical thinking
vernacular error	■ Lack of sensitivity to language and text ■ Misinformation from learning materials or teaching activities	■ Comparative analysis of terms ■ Choose learning materials of better quality

More detailed examination of the context of misconceptions and remedies can be a valuable follow-up to this study.

6. Conclusions

In the age of climate change, energy is a critical issue that may have decisive impacts on anthropogenic GHG emissions and the resulting temperature rise, extreme weather, etc. Energy issues are complex as they are not just about science, but also about people's daily lives, along with related economic and social issues. Moreover, energy is about decision-making, and hence energy literacy plays a crucial role as well-informed and well-educated citizens are the basis for the design and implementation of smart and forward-looking policies. In addition to cognitive knowledge, affective and behavioral aspects are also included in energy literacy. People with energy literacy are expected to take responsible action according to their knowledge and constructed values. However, on the other hand, existing misconceptions about energy may result in biased communication that would lead to people's preference for or objection to specific energy options. It was also argued that the misconceptions of young students may persist into adulthood.

In this study, energy literacy scales with components, subcomponents, and indicators were developed based on an extensive literature review and focus groups. The energy literacy scales included three components, "energy knowledge", "energy and life", and "citizen responsibility and action", seven corresponding sub-components, and 18 indicators. A questionnaire was then developed following a relatively comprehensive procedure in which ad hoc approaches were used for ascertaining the reliability and validity. The questionnaire with questions categorized as "knowledge" and "attitude and action" was distributed to 1562 junior high school students in five regions in Taiwan. A total of 1231 effective samples were collected, resulting in an effective response rate of 75.4%. In addition to descriptive statistical analysis, data collected were also analyzed using independent samples *t*-test and one-way ANOVA for understanding the correlations between components and background variables. In general, student respondents were relatively familiar with topics taught in schools but did not know much about in-depth scientific issues. Moreover, they had a positive attitude and intention toward energy. Students whose parents had a higher education level or worked in education had significantly better knowledge than other students. A declining intention to take energy conservation-related action was also seen among the junior high school students.

It was observed from the survey that students tended to score worse with respect to those questions related to specific misconceptions, regardless of their total score in knowledge. Thus, questions for interviews were designed to correspond to select survey questions. Ten students, nine from Northern and one from Southern Taiwan, were selected as participants. Misconceptions about energy were identified using the six patterns, "intuitive judgement" (Pattern A), "lack of knowledge" (Pattern B), "mistakes from experiences of daily lives" (Pattern C), "misleading from teaching" (Patter D), "logical fallacy" (Pattern E), and "vernacular error" (Pattern F). Two kinds of conceptual logic maps were developed for illustrating how energy issues, participants, diagnosis of misunderstanding, and misconception patterns were linked. Through the issue-oriented misconception analysis and the participant-oriented misconception analysis, it was found that misconceptions were commonly held by most of the students. In addition, the misconception identification technique developed in this study can help illustrate the whole picture of what misconceptions a person holds, as well as why and how these misconceptions develop. These can be used as an important reference for designing effective educational strategies to improve students' energy literacy. Some potential educational strategies were proposed in this study, but further studies should be conducted to link the diagnosis and treatment of misconceptions.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Correlations among the components of "energy and life" and "citizen responsibility and action".

Component		Subcomponent 2-1 (K): Development and Use of Energy	Subcomponent 2-1 (AC): Development and Use of Energy	Subcomponent 2-2 (K): Decision Making about Energy	Subcomponent 2-2 (AC): Decision Making about Energy	Subcomponent 2-3 (K): Energy Issues and Worldview	Subcomponent 2-3 (AC): Energy Issues and Worldview	Component 2: Energy and Life
Subcomponent 3-1 (AC): personal awareness and individual actions	Pearson *r*	0.002	0.021	0.048	**0.298** **	0.019	**0.111** **	**0.150** **
	significance	0.938	0.456	0.095	**0.000**	0.505	**0.000**	**0.000**
Subcomponent 3-2 (AC): citizen participation	Pearson *r*	−0.004	−0.018	0.036	**0.275** **	−0.013	**0.263** **	**0.156** **
	significance	0.890	0.524	0.204	**0.000**	0.642	**0.000**	**0.000**
Component 3: citizen responsibility and action	Pearson *r*	−0.001	0.002	0.045	**0.310** **	0.003	**0.202** **	**0.166** **
	significance	0.974	0.953	0.112	**0.000**	0.913	**0.000**	**0.000**

Notes: ** $p < 0.01$

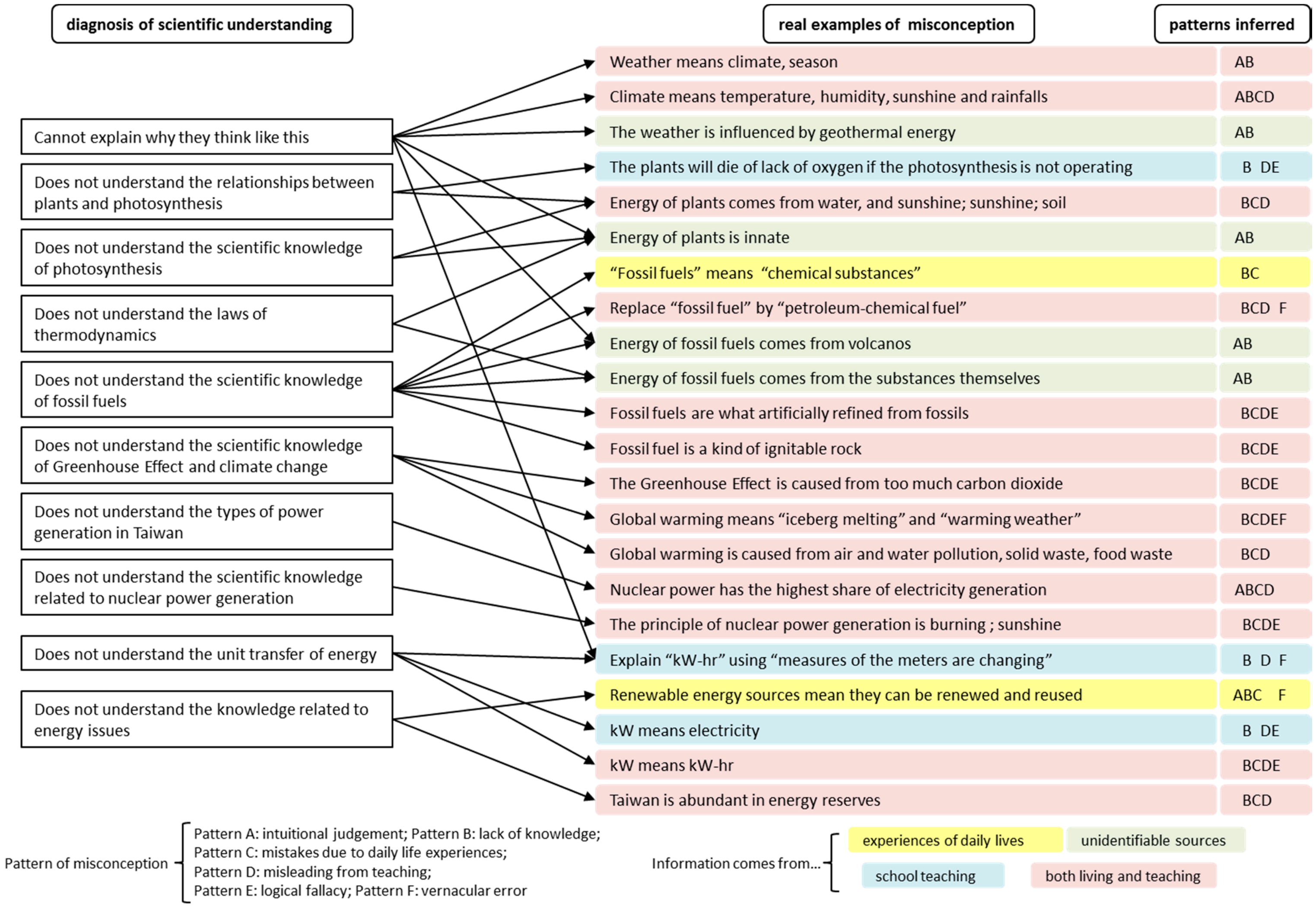

Figure A1. The relationships among the diagnosis of scientific understanding, real examples of misconception, and inferred misconception patterns.

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