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ANALYSIS OF KOREAN MIDDLE SCHOOL STUDENTS' SCIENTIFIC INTERPRETATION DIFFERENCES WITH OR WITHOUT ARROWS IN THE ENERGY PYRAMID

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ABSTRACT

This study analyzed differences in Korean middle school students' scientific interpretation of the energy pyramid diagram, which is a central concept of ecosystem learning, based on whether or not arrows were presented in the chart. Two classes that did not show statistically significant differences in school science academic achievement were selected. One class was shown the energy pyramid diagram with arrows, and the other without. A quasi-experimental design was adopted for quantitative research. The study found that the group interpreting the energy pyramid with arrows had a statistically significant scientific interpretation than the group interpreting the energy pyramid without arrows. In other words, arrows aided understanding of the concepts of size, biomass, and energy transfer of biological elements in the energy pyramid. In addition, the arrows aided understanding of the meaning of each piece of a pie chart, as the amount of biomass or energy being transferred to the next level of nutrition as pieces of a pie chart. Thus, it was concluded that the arrows in the energy pyramid were efficient visual elements in conveying the flow of matter and energy between living creatures. Based on the results, this study recommends that science textbooks should use arrows for more efficient understanding of scientific phenomena throughout textbooks beyond only the "ecosystem" topic.

Keywords: scientific interpretation; energy pyramid; arrows; pie chart

INTRODUCTION

In science textbooks, various diagrams, which are a mixture of language and visual elements, have been used as powerful tools for the delivery of scientific information (Agrawal et al., 2011; Tippett, 2016). In particular, biology textbooks contain numerous diagrams complementing written text to visually express meaning or provide supplementary information. In this way, the use of a mixed diagram of visual representation and written text is the most common method used in modern science textbooks. In other words, science textbooks include strategies that help learners understand key science concepts through diagrams (Khine & Liu, 2017).

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Science helps students understand learning by presenting models or diagrams of phenomena that cannot be observed by the eye. In addition, the data obtained through inquiry can be expressed more easily using diagrams (Kim, 2020). Science explains scientific phenomena through various diagrams, which in turn help learners understand what science is by presenting symbols together. Therefore, differences can arise in the direction and interpretation of students' approaches to science, depending on whether or not certain symbols are presented in the diagram to express scientific phenomena. Previous studies have identified how certain symbols have a great influence on learners' understanding of scientific phenomena and concepts (Pozzer-Ardenghi & Roth, 2004; Wright et al., 2017).

Among many symbols, arrows, in particular, have been reported to be effective visual design elements for promoting scientific thinking and conveying scientific research processes and the flow of certain phenomena (Hmelo-Silver & Azevedo, 2006; Eilam & Gilbert, 2014). The arrows in diagrams could help learners to interpret more functions dynamically in the system. In other words, a diagram consisting of simple text without arrows is more likely to remain in a static structure and description than in a dynamic representation between components in the system (Heiser & Tversky, 2006; Eilam & Gilbert, 2014).

In particular, as complicated and various concepts are integrally applied to ecosystem-related topics (Jin et al., 2019; Liu et al., 2019), several different visual diagrams help learners better understand the mutual relationships between biological and non-biological elements in the ecosystem. However, even splendid visual diagrams can be useless, if be presented without the factors that play an important role in scientific interpretation in the ecosystem. Moreover, if science teachers approach visual diagrams only from a macroscopic perspective, even with a variety of symbols, such as arrows, the meaning could be overlooked (Novick, 2006; Liu & Khine, 2016).

Among the various subdomains of science subjects, topics related to ecosystems are very spacious and diverse in scope, and comprise simultaneous and dynamic interaction of various earth components (Kim et al., 2015; Kirsop et al., 2021). Scientific concepts of an ecosystem are not formed by understanding only one particular concept, but by the interaction of the various elements that make up the ecosystem. Most importantly, the ecosystem is a concept directly related to human life, and it is necessary to thoroughly examine even crisis elements, which may be changed by human influence or have an effect on human beings (O'Brien et al., 2018). The use of structured diagrams is essential for understanding the ecological phenomena that have these characteristics. Pyramids are an essential concept for dealing with the theme of energy transfer and flow, which is central to ecosystem learning (Eilam, 2013). South Korea's 2015 revised science and education curriculum emphasizes understanding the maintenance of ecological equilibrium and the interactions between organisms around the ecological pyramid. However, the concept of pyramids in ecosystems involves a complex interrelationship between energy conversion, flow, and loss, making it difficult for students to fully understand the concept of pyramids (Eilam & Poyas, 2010). Therefore, it is important to use symbols that can influence concept understanding, such as arrows, in energy pyramids that contain energy concepts. However, research on biological textbooks has revealed that some textbooks use arrows in energy pyramids to convey the direction of energy flow or energy loss, while some textbooks do not (Ge et al., 2014).

The purpose of this study is to examine differences in Korean middle school students' scientific interpretation of the energy pyramid depending on whether the arrows are presented or not. At present, research on students' understanding of the energy pyramid in Korea is limited. Han & Kim (2012) identified the concept level of ecological equilibrium through the feed pyramid model for elementary school students in Korea and recommended the use of in-depth discussion on models that could explain the equilibrium of the ecosystem. Han & Choi (2013) reported that Korean students neither understood nor misunderstood the concept of ecosystems; in particular, they did not recognize the importance of environmental factors that made up ecosystems, and did not accurately understand the concept of energy movement. As such, Korea's previous research has aimed to identify students' understanding and misconceptions about each element and concept related to ecosystems. However, no studies have been conducted on the role of specific symbols, such as the arrows included in the diagram and the type of diagrams used in ecosystem learning. In addition, the concept of pyramids in ecosystems tends to be seen as research and teaching guidance focused on ecosystem equilibrium through food pyramids or population pyramids.

However, understanding the flow of energy is a prerequisite for understanding the flow of matter in the nutrient cycle in the ecological pyramid. It is necessary to understand the concept that this amount of energy is determined by the efficiency with which food energy is converted into biomass in an ecosystem. In this educational context, ecologists have devised the energy pyramid to explain how energy decreases in the movement from a low nutrient level to a high one (Phelan, 2013). The energy pyramid represents the energy flow from one nutrient level to the next, and shows the energy loss that occurs during the transfer process. Therefore, the learning of the energy pyramid in ecosystem learning is a representative concept in ecosystem learning that provides comprehensive access to the number of trophic levels, food relations, biomass, biological factors, and non-biological factors. The type of teaching-learning materials that teachers use when teaching the energy pyramid has a significant influence on learners' understanding of the overall contents of the ecosystem (Toman, 2018). It is necessary to conduct energy pyramid learning systematically based on diagrams that include various signs (Yucel & Ozkanz, 2015; Wilks & Harris, 2016). Thus, understanding the role of arrows in these energy pyramids has important implications for the teaching and learning strategies of ecosystems. Thus, this original study could provide a foundation for researchers of follow-up studies on ecosystem-related teaching and learning methods. The results could provide guidance for the use of symbols in science and have implications for developing and presenting visual diagrams in ecosystem learning.

This study considers the following research questions. First, is there any difference in students' understanding of biological factors based on whether arrows are presented in the energy pyramid?; second, is there any difference in students' interpretation of the pieces of the pie in a chart based on whether arrows are presented in the energy pyramid?

METHODS

In this study, third-grade middle school students in a metropolitan city in Korea were examined for their understanding of the level and content of the energy pyramid. In Korea's 2015 revised science curriculum, the learning pyramid for 6th-grade elementary school students falls under the chapter "Ecosystem and Environment," while further learning about ecosystems takes place under the chapter "Biodiversity" in the middle school science curriculum. To adopt a systematic approach to the energy pyramid, researchers have found that middle school students who gradually learn about ecosystem diversity are more suitable for this type of research than elementary school students who first learn about the pyramid.

The purpose of this study was to determine the differences in scientific interpretations of the energy pyramid with or without arrows. Thus, we selected two classes that did not show statistically significant differences in academic achievement between the school regular science midterm exams or the final exams. In one class, 32 students were shown an energy pyramid diagram with arrows, and in the other class, another 32 students were shown an energy pyramid diagram without arrows. In other words, non-probability sampling was adopted, and research subjects were intentionally collected based on their academic achievements. This study adopted a quasi-experimental design for our quantitative research. Both classes were taught by one science teacher.

To determine the difference in middle school students' scientific interpretation of the arrows presented in the energy pyramid, the energy pyramid diagram developed by Phelan (2013) and the questions constructed to understand the energy pyramid were used. The energy pyramid developed by Phelan (2013) has arrows, but for the purposes of this study, an additional image without the arrows was constructed (Figure 1).

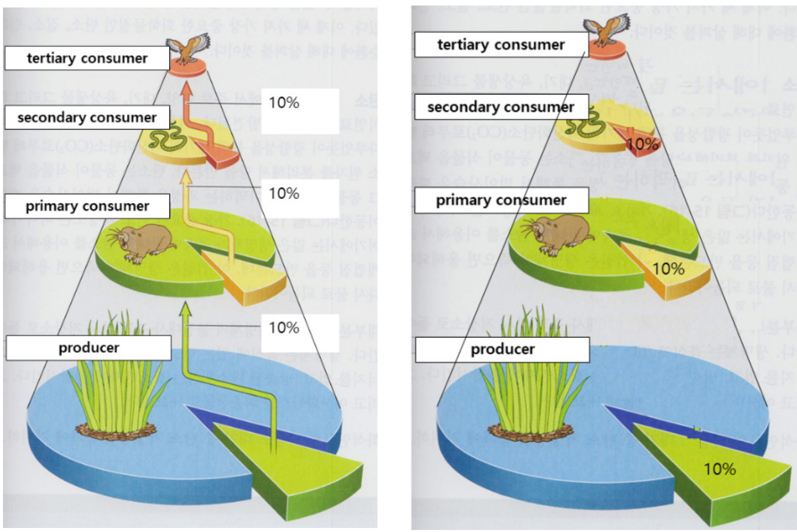

Figure 1. Energy Pyramid With and Without Arrows (Phelan, 2013)

The test questions for identifying the energy pyramid were divided into two categories. The first category consisted of three questions for the interpretation of the biological factors, and the second category contained three questions for the interpretation of pieces of a pie chart showing the biomass of each nutrient level (Table 1). Through a pretest with five middle school students (who were not among the research subjects), the suitability of this test was confirmed.

Table 1. Test Tool for Energy Pyramid Analysis

Categories	Test Questions
Interpretation of biological factors	1. Why is the size of a hawk drawn smaller in this diagram than the sizes of the other creatures?
	2. How would the picture of the consumer change if consumers who ate both plants and animals were included?
	3. What can be concluded from this diagram about the relative number of carnivores and herbivores?
Interpretation of pie slices	1. What do the pie slices mean in this diagram?
	2. In this diagram, what does the size of the pie slice mean and why is it not the same?
	3. Why aren't pie slices drawn in the last phase of the nutrient cycle?

(Phelan, 2013)

The first step in the test procedure was to present a diagram of the energy pyramid with or without arrows to the two groups of students (group A: diagram with arrows; group B: diagram without arrows). Each diagram was carefully monitored for 10 minutes. The process was conducted under the supervision of the science teacher, who participated in this study's analysis. The second step involved asking six questions about the interpretation of the energy pyramid. Students could freely write on an open answer sheet for 35 minutes. There was no limit to the length of answers, but students were asked to provide answer sheets with key words that they should use.

Since all the test questions were descriptive, to reliably analyze the responses, researchers and one of the secondary school science teachers (the science teacher in charge of the science class for the study) analyzed the results separately. After each analysis, the results were compared, discrepancies discussed, and the agreed results were examined. For science concepts, two analysts prepared exemplary answer sheets and extracted key words from them in advance, based on content from either science textbooks or biology-specialized books. They then checked whether the key words were included in the students' answers first, and then tried to comprehend the overall context of their answers. Each analyst tried to understand the meaning of the description by repeatedly reading the sentences described by the students and analyzing their sentences several times.

The study aimed to determine whether there were statistically significant differences in the average value between the groups regarding scientific interpretation (correct answers) of the questions. The results were examined using a t-test. One point was earned for a scientific interpretation (correct answer) for each question, and zero points were used awarded for a non-scientific interpretation (incorrect answer). Unscientific interpretations (incorrect answers) included the absence of an answer. In addition, for each question, the answer rate for scientific interpretation was presented and discussed.

RESULTS AND DISCUSSION

The result of the t-test is shown in Table 2. It shows whether there is a statistical difference of the average values for the correct answers (scientific interpretation) between group A interpreting the energy pyramid with arrows and group B interpreting the energy pyramid without arrows.

Table 2. t-test Results for Interpretation Results of Biological Element Questions

Group	Average	Standard deviation	t	p
Group A (energy pyramid with arrows)	1.96	1.14	2.145	.036*
Group B (energy pyramid without arrows)	1.34	1.18		

*p<.05

The t-test shows that there is a statistically significant average difference between the two groups (p<.05). Therefore, the presence or absence of arrows in the interpretation of the energy pyramid was influenced, and the arrows aided understanding of the concept of size, biomass, and energy movement of biological elements in the energy pyramid. The results comparing the percentage of correct answers for each question about the biological factors are shown in Table 3.

Table 3. Correct Answer (Scientific Interpretation) Rate of Biological Factors

Test Questions	Scientific Interpretation	Correct Answer (Scientific Interpretation) Rate (persons(%))	
		Group A (32 person)	Group B (32 person)
1. The size of a hawk	The size of the biologic component in each phase represents the relative quantity of biomass, so that the biomass moving from the producer to the tertiary consumer decreases. Thus, the final consumer, the hawk, is drawn the smallest.	22(68.75)	15(46.87)
2. Picture shape when including consumers who eat both animals and plants	Eating both plants and animals leads to accumulation of 10% of the biomass for each animal and plant, representing a larger image than any other consumer. In other words, biomass is the largest.	20(62.50)	13(40.62)
3.Relative number of carnivores and herbivores	The number of predators is much smaller than that of herbivores. This is because the total biomass of predators is only one-tenth of the total biomass of herbivores.	21(65.62)	13(40.62)

For the first question related to the size of a hawk, 22 out of 32 students (68.75%) in the group that was shown the energy pyramid with arrows provided a scientific interpretation. Meanwhile, in the group that was shown the energy pyramid without arrows, 15 out of 32 students (46.87%) provided a scientific interpretation. Arows were displayed in the energy pyramid to explicitly indicate the relative amount of biomass movement at each level of the producer, primary, secondary, or tertiary consumer. Showing the small size of the falcon helped understanding, because the amount of biomass that could move to the next level was reduced by that much when reaching the third consumer. Biomass refers to the weight and amount of energy of an entire organism, whether living or not, such as the weight of all plants and animals in an ecosystem (Phelan, 2013). Therefore, understanding the meaning of biomass aids understanding of the transition of 10% biomass from a previous phase in the nutrient cycle, and the use of arrows could be used as a teaching learning strategy to show the transition.

In the second question, about consumers who ate both plants and animals, 20 people (62.50%) in Group A, which were shown the energy pyramid with arrows for the size of the consumer, gave scientific interpretations while 13 people (40.62%) in Group B, who were shown energy pyramids without arrows, gave scientific interpretations. The result shows that understanding increased with the use of arrows to indicate the shift of energy and biomass to upper nutrient levels and that the biomass of the consumer increased if energy and biomass were received from both producers and consumers.

Regarding the third question about the relative numbers of carnivores and herbivores, 21 students (65.62%) of group A had scientific interpretations, and 13 students (40.62%) of group B had scientific interpretations. Group A's scientific interpretation rate was high. In other words, the students in this group clearly understood that the amount of energy was one-tenth of the biomass moving to the predator by the use of arrows to carnivores, which clearly helped students provide the scientific interpretation that the number of predators was only small. On the one hand, the scientific interpretation of this question could explain why end-consumer carnivores require a huge amount of producers and biomass of the previous consumer to survive.

As the level of the end-user goes up, there are bound to be fewer numbers, which explains why vegetarian food has better energy efficiency than a diet with meat. Therefore, the arrows were identified as an efficient visual clue for interpreting the energy pyramid. Arrows, as visual elements, convey meaning associated with a series of visual designs and supplementation of text, flow of a particular material, or geometric properties (Heiser & Tversky, 2006). Arrows can be used to supplement text dealing with unclear scientific phenomena through text alone. Thus, energy pyramids using such arrows could develop students' ability to identify the various interrelationships of ecosystems and to predict the causality of systemic behavior (Eilam, 2013). In particular, the ecosystem is a large system in which several elements are circulated in relation to one another (Han & Choi, 2013; Aikens & McKenzie, 2021). In this context, arrows in energy pyramids are effective for explicitly expressing the relationship of biological components, which could help to develop a systematic approach between ecosystem components. However, among the group of students who were shown the arrows, not all students related the arrows to the meaning of biomass and energy transfer owing to the difficulty in interpreting the arrows. Therefore, it was necessary to combine various symbols in the energy pyramid, present additional texts, and diversify the types of arrows as an effective strategy to help these students interpret the arrows. In this educational context, ecosystem-related education requires special teaching strategies (Ikhsan et al., 2019; Suryawati et al., 2020).

The results of the t-test to observe whether there was a statistically significant difference between the interpretations of the pieces of the pie chart questions by Group A and Group B are shown in Table 4. The average score for Group A was much higher at 1.84 than that for Group B at 1.21. These differences were statistically significant ($p<.05$). Thus, the arrows helped understanding of the biomass or amount of energy transitioning to the next phase in the nutrient cycle as pieces of the pie chart.

Table 4. Results of t-test on Interpretation of Pieces of the Pie Chart Questions

Group	Average	Standard Deviation	t	p
Group A (energy pyramid with arrows)	1.84	1.13	2.178	.033*
Group B (energy pyramid without arrows)	1.21	1.15		

*$p<.05$

The results of the analysis of correct answer rates for each question regarding the interpretation of pie slices are shown in Table 5.

Table 5. Correct Answer (Scientific Interpretation) Rate of Pieces of the Pie Chart

Test Questions	Scientific Interpretation	Correct Answer (Scientific Interpretation) Rate (persons(%))	
		Group A (32 person)	Group B (32 person)
1. Meaning of pie slices	Each pie slice is 10% of the total pie, and shows the efficiency of converting one nutrient phase of the energy pyramid to the next.	19(59.37)	13(40.62)
2. Meaning of pie slice size	Pie slice size represents biomass, and shows that the pie is reduced by one-tenth each time it progresses to the next nutrient phase.	19(59.37)	14(43.75)
3. Reason there are no pie slices in the last nutrient stage	Since only 10% of the biomass is converted to each of the next nutrient phases, the amount that can be transferred to the fourth consumer is very limited.	21(65.62)	12(37.50)

In the first question, 19 people (59.37%) in group A gave scientific interpretations for the meaning of the pie slices, and 13 people (40.62%) in group B gave scientific interpretations. Group A, which was shown the arrows in the energy pyramid, tended to understand that pie slices were 10% biomass, and that the efficiency of the biomass transition to the next phase was also 10%. In the second question on the meaning of the size of the pie slices, 19 people (59.37%) in group A, and 14 people (43.75%) in group B gave scientific interpretations. The size of the pie slice represented biomass, and the size of the pie in each nutrient phase was one-tenth that of the previous phase. The arrows indicate that 10% of the biomass in the previous nutrient phase is converted to the next nutrient level, which could help interpret the meaning of the pie slice size. Meanwhile, to clarify that only 10% of the total is transferred to the next nutrient phase, the arrows could show that 90% is lost through consumption or excretion by cell respiration while only 10% is used for new growth, it would enhance understand of the 10% biomass transformation.

In the third question, 21 students (65.62%) in group A and 12 students (37.50%) in group B gave a scientific interpretation for the absence of pie slices in the final nutrient phase of the energy pyramid. The biggest difference was found in the percentage of correct answers compared to the other questions. The use of arrows helped students recognize that 10% of the biomass continued to move to the next nutrient level, illustrating a shortage of biomass that can be converted from the third to fourth level of consumer. Because of energy lost during the actual cell respiration process, the amount of biomass delivered at each level of the food chain is only about 10% of the biomass consumed as food. Because of this inefficiency, the food chain rarely progresses beyond four levels (Phelan, 2013). Arrows are an effective visual element when conveying concepts, such as position, direction, and transition. This study shows that arrows lead to more functional interpretation as well as a more efficient interpretation of the meaning of scientific phenomena.

This result is consistent with Heiser & Tversky's (2006) argument that arrows can help learners interpret more functions in an energy pyramid diagram. It is also consistent with Kesidou & Duit's (1993) and Preston (2018) result that arrows are effective aids for understanding concepts about the flow of matter and energy between creatures, which have previously proved difficult for learners to learn the energy pyramid. In science education, visual materials assist textual explanations through the visualization of learning content and conveys them effectively so that students remember them for a long time (Pozzer-Ardenghi & Roth, 2004; Jung & Lim, 2018). In particular, in terms of cognitive psychology, the use of such symbols as arrows enables text information to be combined with image information, helps learners adopt integrated approaches to such information, and even improves their cognitive activities through visualization (Krum, 2014). Overall, using arrows in science diagrams aids learners' cognitive activities and enables them to adopt sequential approaches to scientific concepts.

Overall, the results show that energy pyramid learning helps students better understand scientific concepts through various diagrams and arrows. Thus, teachers should improve their teaching competencies for developing diagrams of science concepts (Eromosele & Ekholuenetale, 2016; Kobori et al., 2016).

CONCLUSION

The conclusions based on the results of this study are as follows. Energy pyramids with arrows were found to be effective in helping students interpret the meaning of energy flow and biomass conversion. The arrows helped students recognize the movement of biomass as an energy source. As for the interpretation of biological factors as a subcategory of tests, the analysis also indicated that if the diagram included the size of a hawk shown as a tertiary consumer as well as a consumer who ate both plants and animals, the picture would help students' scientific interpretation through the use of arrows. The analysis of subcategory pie slices indicated that an energy pyramid with arrows aided scientific interpretation of the meaning of the pie slices, the size and meaning of the pie slices, and why there is no pie slice in the last nutrient phase. In this study, the difference in the interpretation of the energy pyramid with and without arrows was examined, but understanding the energy pyramid requires learning through the linkage between the food chain and the food web. Therefore, further research needs to be conducted to determine whether students understand the meaning of arrows in the food chain and the food web. It is necessary to further consider the accuracy of arrow expressions in science textbooks and to clarify the significance of arrows in ecosystem composition based on the importance of the overall expression of arrows in the curriculum of the ecosystem and environment.

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