

RESEARCH ARTICLE

Learned Concept Networks in the Components of an Ecosystem based on Students' Science-Related Attitudes Levels

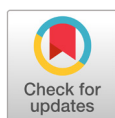
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ABSTRACT

Science-related attitudes are known to influence students' science learning. However, the specific reasons of science learning differences based on science-related attitudes have not yet been identified. Therefore, this study aims to investigate the reasons for these differences in science learning at the conceptual level by analyzing the learned concept networks learned by students according to their levels of science-related attitude. This study compared and analyzed the learned concept networks according to students' science-related attitude levels, alongside the inter-subtopic and intra-subtopic connection concept networks, across different attitude levels. A science-related attitude test was administered to 298 10th graders, and learning memory tests were conducted immediately and four weeks after the class to measure the level of science learning regarding topics related to ecosystem composition. The ecosystem composition topics were categorized into "the components of an ecosystem" and "the interactions between ecosystem components." The results showed that students formed network of key concepts centered on similar, specific concepts regardless of topic, but the structure of these networks and the strength of connections between concepts varied. Students with lower-level group of science-related attitudes tend to remember fewer concepts, and subsequent learning significantly influences the conceptual structure of prior learning. Therefore, these findings suggest that for students in lower-level group, it's necessary to present key concepts in a 'chunk form', linking them together, and consistently repeat key concepts. Furthermore, teaching and learning methods that clearly explain the connection between subsequent learning and prior learning are needed to enhance retention.

Keywords: Science-related attitudes, learned concept network, connection concept network, the components of an ecosystem, interactions between components of an ecosystem, 10th graders



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Introduction

Affective factors related to science exert both direct and indirect influences on science learning. Among these, science-related attitudes are recognized as a key factor (Chi & Wang, 2023; Chiappetta & Koballa, 2002; Kim & Kim, 2012; Mao et al., 2021; Martin et al., 2002). Science-related attitudes is a concept that integrates “attitudes towards science” and “scientific attitudes” (Kim et al., 2025). Attitudes towards science refer to dispositions regarding science or scientific issues, encompassing values, beliefs, thoughts, and feelings. Scientific attitudes refer to the mindset of a scientist—characterized by a disposition for inquiry and analysis—and the approach taken when evaluating new ideas and knowledge, solving problems, and selecting opinions (Kim et al., 2025). Research in this area has primarily focused on instructional methods to enhance science-related attitudes and the relationship between these attitudes and academic achievement (Kim et al., 2020; Lee & Kwon, 2022; Norris & Philips, 2003; Park et al., 2017). However, such studies have limitations in identifying the specific underlying reasons for how science-related attitudes influence science learning. Building on the finding that science-related attitudes significantly affect conceptual understanding (Anggraini et al., 2022), this study sought to identify these specific causes by comparing the understanding of learned concepts based on the learners’ levels of science-related attitudes.

Science learning is the process of constructing scientific concepts within a learner’s cognitive structure. This process occurs when learners actively engage in cognitive activities—such as selecting relevant scientific information, organizing that information into a coherent cognitive structure, and integrating new knowledge with existing scientific knowledge retrieved from long-term memory (Mayer, 2014; Southerland et al., 2006). In other words, because science learning involves linking new scientific concepts to existing ones and structuring these connections meaningfully, learners face difficulties if they lack core scientific concepts or fail to accurately structure the connections between them (Kim et al., 2023). Consequently, efforts to map the structure of concepts within a learner’s cognitive structure continue, as doing so offers valuable insights into the science learning process (Lim et al., 2025).

Semantic network analysis is a research method that constructs and examines a network based on the structure of concept usage to analyze various aspects of semantic associations (Krackhardt, 1992; Park, 2021). Grounded in Atkinson and Shiffrin’s (1968) memory theory—which posits that concepts (components of information processing such as short-term and long-term memory) are interconnected—this method is primarily used to identify the structural relationships between concepts within a learner’s cognitive framework. It structures the relationships between concepts as a network by representing each concept presented when a learner discusses a topic as a node and the connections between them as links. This approach offers the advantage of concretizing abstract conceptual structures and enabling the analysis of the strength of relationships between key concepts (Zafarani et al., 2014). Consequently, this analytical method is widely employed to examine learners’ concepts (Koponen & Nousiainen, 2014; Park, 2018), analyze learners’ perceptions (Kenett & Faust, 2019; Son & Kim, 2013), assess curriculum alignment (Kim et al., 2022; Kim et al., 2023; Park et al., 2018), and analyze the relationship between concepts taught by teachers and those learned by students (Lim et al., 2025).

Learning is primarily measured through the retention of knowledge presented during instruction and the transfer of acquired knowledge, as transfer serves as a key indicator of successful learning. Consequently, to determine whether

learning is meaningful rather than based on rote memorization, it is necessary to assess the extent of retention after a period of time has elapsed (Johnson & Mayer, 2009). However, most studies tend to evaluate learning outcomes immediately following instruction. Since results obtained immediately after learning often reflect knowledge that resides temporarily in working memory or has not yet fully consolidated into long-term memory, it is essential to verify the traces of consolidated long-term memory where new scientific knowledge has been integrated with existing knowledge (Schweppe et al., 2015). Therefore, to ascertain whether scientific knowledge has been successfully integrated into students' cognitive structures, assessments should be conducted after a time interval following the instruction (Schweppe et al., 2015). Accordingly, this study examined the concepts learned by students both immediately after the class and four weeks after the class.

Modern society faces a serious crisis due to rapid climate change, leading to growing interest in ecosystems and the environment (Im & Park, 2024). An ecosystem is a system in which biotic and abiotic environmental factors do not exist in isolation but maintain a dynamic equilibrium through complex interactions among their components. Humans, too, occupy the role of consumers within the ecosystem and coexist through interactions with other organisms and environmental factors (Evagorou et al., 2009; Lee et al., 2019). Therefore, for students to form accurate scientific concepts regarding ecosystems, they require “systems thinking”—an approach that comprehensively grasps not only the interactions between components but also the dynamics of the system's overall structure (Arndt, 2006; Eilam, 2012; Jacobson & Wilensky, 2006). The semantic network analysis method employed in this study is well-suited for analyzing the patterns of systems thinking structured within students' cognitive frameworks (Kim & Lee, 2022). Accordingly, the topic of “Ecosystem and the Environment” unit in the high school Integrated Science under the 2015 revised national curriculum was selected for this study.

Therefore, the purpose of this study was to analyze the conceptual networks formed by 10th-grade students based on their levels of science-related attitudes. To this end, the concept networks learned by the students were visualized both immediately after class on the “Ecosystem and Environment” unit and four weeks after the class. Additionally, to facilitate a comparison of learned concepts based on science-related attitude levels, differences in learned concepts—both between subtopics and by subtopics—were visualized using connection concept networks. The research problems for this study are as follows:

First, how do students' concept networks for the “Ecosystem and the Environment” unit—formed immediately and four weeks after the class—differ according to their levels of science-related attitudes?

Second, what are the differences of the inter-subtopic and intra-subtopic connections within the connection concept networks formed by students immediately and four weeks after the class, based on their levels of science-related attitudes?

This study is significant in that it investigates the aspects of science learning from a conceptual perspective, based on learners' levels of science-related attitudes, and explores their implications for subsequent instructional strategies and methods.

Theoretical Background

Science-related Attitudes and Science Learning

Developing a positive attitude toward science is one of the core objectives in science education, along with the acquisition of scientific knowledge, inquiry skills, and scientific thinking (Ministry of Education, 2015). Science-related attitudes encompass both “attitudes toward science,” which refer to a disposition toward science as a discipline or toward scientific issues, and “scientific attitudes,” which represent the scientific mindset and approach to addressing scientific problems (Kim et al., 2025).

Extensively studied as a critical factor influencing students’ science learning, science-related attitudes have particularly been linked to academic achievement. Recent studies (Mao et al., 2021; Rho & Ryoo, 2022) have demonstrated that attitudes toward science not only exert a direct positive impact on science achievement but also indirectly affect it through various mediating variables, such as teacher academic support. Students’ positive scientific attitudes have likewise been shown to directly enhance their academic outcomes (Park et al., 2017). Consequently, continuous efforts have been made to develop instructional methods aimed at fostering these attitudes (Kim et al., 2020; Lee & Kwon, 2022). However, empirical research identifying the specific, underlying mechanisms through which science-related attitudes lead to variations in academic achievement remains scarce.

Grounded in previous study indicating that science-related attitudes exert a profound influence on the understanding of science concepts (Anggraini et al., 2022), this study aims to analyze the variations in academic achievement resulting from these attitudes at a conceptual level. Specifically, by comparatively analyzing the structural differences in the concept networks formed by students across different levels of science-related attitudes, this study seeks to elucidate the specific, underlying causes of the variance in academic achievement from a conceptual perspective.

Ecosystem-related Science Curriculum

In Republic of Korea, the 2015 Revised National Curriculum is currently in effect. In the 2015 Revised Science Curriculum, the integrated curriculum presents ecosystem-related content in the 10th-grade Integrated Science unit titled ‘Ecosystem and the Environment.’ The core achievement standard directly related to ecosystems states: “Students can understand the interactions between organisms and the environment, alongside the components of the ecosystem including humans, and infer the necessity of conserving the ecosystem for human survival” (Ministry of Education, 2015). Regarding ecosystem components, the curriculum specifies that populations and communities are mentioned only at a conceptual level, while interactions within a population or community are excluded. In most Integrated Science textbooks, this core achievement standard is divided into two separate class blocks: “the Components of an Ecosystem” and “the Interactions between Components of an Ecosystem.” The former defines the ecosystem and introduces biotic and abiotic factors, whereas the latter details the reciprocal interactions between these factors. Accordingly, this study analyzed the content by dividing it into these two designated subtopics.

Examining the U.S. Next Generation Science Standards (NGSS), which are directly relevant to “Ecosystem and the Environment,” the Performance Expectations include: “Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but

changing conditions may result in a new ecosystem” (HS-LS2-6). Furthermore, the Disciplinary Core Ideas (DCIs) of the NGSS correspond directly to LS2.A: Interdependent Relationships in Ecosystems, which falls under the broader life science core idea framework of LS2: Ecosystems: Interactions, Energy, and Dynamics.

Research Methods

Research Design

The purpose of this study was to analyze the structural differences—specifically the relationships among learned concepts—regarding the topic of “Ecosystem and the Environment” in Korean high school Integrated Science, based on students' levels of science-related attitudes. To achieve this, a quantitative research design was employed. The participants were sampled from three high schools in the Republic of Korea, where the students' overall academic achievement falls into the upper-middle tier nationally. As the “Ecosystem and the Environment” unit is divided into two subtopics—“the Components of an Ecosystem” and “the Interactions between Components of an Ecosystem”—the instruction was implemented from the first week of October to the second week of December 2024, aligned with each school's academic schedule. Each subtopic was taught in a 50-minute session using a teacher-centered, lecture-based approach. Following the instruction, participants completed a science-related attitude test and a learning memory test. To assess long-term memory retention, the learning memory test was administered twice: immediately and four weeks after the class. The collected data were then subjected to network analysis.

Subjects

This study was conducted with high school teachers and students who consented to the research purpose and methods. The participating schools consisted of three high schools located in metropolitan city “D,” which has a population of over 2.8 million; the academic achievement level of the participants corresponds to the mid-tier nationally. The teachers at the participating schools were all female, with teaching experience ranging from 5 to 10 years, and two of them held a master's degree. A total of 298 tenth-grade students were initially sampled. To construct a reliable learned concept network, a census sampling approach was utilized to survey all students within the participating schools. Ultimately, the final analysis included only those students who completed all three assessments: the science-related attitude test, and the learning memory tests administered immediately and four weeks after the class.

Regarding the science-related attitude test, 87 students who provided straightlined responses (e.g., selecting “3” for all items) and 44 students with missing values (at least one blank item) were excluded. Consequently, a preliminary dataset of 167 students was obtained. From this pool, the analysis only included students who diligently completed both follow-up tests administered immediately and four weeks after the class for each subtopic. However, despite meeting the aforementioned criteria, students who merely listed isolated concepts on the learning memory test were also excluded. Because this study aimed to analyze the contextual connections between concepts within sentences using co-occurrence frequencies rather than simply tracking raw word frequencies, lists of isolated concepts yield data from which contextual relationships cannot be meaningfully derived (Popping, 2000). As a result, the final analyzed sample consisted of 85 students (43 males, 42 females) for “the Components of an Ecosystem” and 71 students (30 males, 41 females) for “the

Interactions between Components of an Ecosystem.” When the sample size for semantic network analysis exceeds 15, it can be considered a sufficient sample based on evidence showing a high correlation of more than 90% with the population (Lim & Lee, 2013).

Class Contents

The instruction consisted of two 50-minute class blocks based on the “Ecosystem and the Environment” unit of 10th-grade Integrated Science: “the Components of an Ecosystem” and “the Interactions between Components of an Ecosystem.” Aligned with each school’s academic schedule, the lessons were conducted between October and December 2024. Each session lasted 50 minutes and was delivered in the form of a traditional, teacher-centered lecture focusing on textbook concepts.

The class content for “the Components of an Ecosystem” focused on identifying the definitions and examples of biotic and abiotic factors that constitute an ecosystem. The teachers categorized biotic factors into producers, consumers, and decomposers, as well as organisms, populations, and communities, and explained the meaning of each category alongside relevant examples. For abiotic factors, the definitions were explained first, followed by the presentation of examples.

The class on “the Interactions between Components of an Ecosystem” aimed at understanding how biotic and abiotic factors influence one another within an ecosystem. The teachers illustrated these relationships with examples, demonstrating both the impact of biotic factors on abiotic factors and the influence of abiotic factors on biotic factors.

Questionnaire

To measure science-related attitudes and learned concepts, a science-related attitude test and a learning memory test were utilized. First, the science-related attitude test adopted the instrument developed by Kim et al. (1998), which underwent a large-scale national standardization process. Items containing expressions incompatible with contemporary students’ language levels or sentiments were revised without altering their core construct. For this refinement, face validity was verified by a panel of three experts: two PhDs in science education and one practicing high school teacher with a master’s degree in science education. Specifically, a sample item assessing cooperativeness, “In group experiments, I do the work that others dislike doing,” which previously emphasized unilateral sacrifice, was modified to reflect modern collaborative learning as follows: “During group inquiry activities, we fairly divide roles through discussion and participate responsibly.” The science-related attitude test comprises two main domains with 48 items rated on a 5-point Likert scale. It consists of 12 items related to perception and 15 items related to interest within the “attitudes toward science” domain, and 21 items for “scientific attitudes,” allotting 3 items to each of the 7 sub-elements. The reliability of each domain within this instrument ranged from a Cronbach’s α of .826 to .891.

The learning memory test was developed by referencing instruments used in Chun et al. (2024) and Lim et al. (2020), and was subsequently modified and supplemented to suit the “Ecosystem and the Environment” unit through discussions among the same three experts (two PhDs and one practicing teacher). This instrument consists of the learning topic, learning objectives, writing guidelines, and illustrative examples, and was designed to prompt students to describe their learned concepts during class in complete sentences.

Data Collection and Analysis

The data collected in this study comprised science-related attitudes, along with students' learning memory tests administered immediately and four weeks after the class. Students were permitted to respond freely to the tests. The science-related attitude test was conducted one week prior to the instruction under the guidance of science teachers. Responses were collected via an online questionnaire created with Google Forms using tablet PCs or smartphones, taking approximately 10 to 15 minutes to complete. The learning memory tests were administered both immediately and four weeks after the class for each lesson block. Under the teacher's supervision, students completed the digital test forms via tablet PCs or smartphones, which required around 10 minutes.

The total score for the science-related attitude test was calculated by aggregating the scores of both domains: attitudes toward science and scientific attitudes. Items were rated on a 5-point Likert scale, with points ranging from 1 to 5, and negative items were reverse-coded prior to summation. Based on the total score percentiles, participants were classified into three levels of science-related attitudes: high, middle, and low. Specifically, the top 27% were assigned to the high-attitude group, the bottom 27% to the low-attitude group, and the remaining 46% to the middle-attitude group (Chun et al., 2024; Lim et al., 2020). This 27% classification threshold is grounded in Kelly's (1939) foundational study in educational evaluation and statistics, which verified this cutoff point as optimal for maximizing discrimination between groups. Consequently, for "the Components of an Ecosystem," students were classified into the upper level ($n = 22$), lower level ($n = 22$), and middle level ($n = 41$) groups. For "the Interactions between Components of an Ecosystem," the distribution was upper level ($n = 19$), lower level ($n = 19$), and middle level ($n = 33$). In this study, the mean scores were 4.1 for the upper level, 3.5 for the middle level, and 2.8 for the lower level, aligning closely with patterns reported in previous study (Kim & Kim, 2012; Son, 2017).

For the learning memory test, the descriptions written by students in Google Forms were transcribed into text files (.txt). To control for the stylistic variances of textbooks used by different schools and minimize potential textbook effects, the data from all schools were pooled and analyzed as a consolidated dataset rather than being separated by institution. The collected text responses underwent a concept extraction process using the NetMiner 4.0 software. First, to isolate concepts with substantive scientific meaning, grammatical components such as particles, endings, and affixes were excluded, and nouns were primarily selected during the initial screening. Subsequently, demonstrative pronouns (e.g., "this," "that") and contextually non-substantive words (e.g., "thought," "explanation") were removed. Additionally, synonyms were consolidated to ensure conceptual consistency (e.g., merging "soil" and "earth" into "soil"; merging "biotic element," and "biotic factor" into "biotic factor") based on established coding protocols (Kim et al., 2023; Yun & Park, 2018). Through this refinement process, a final set of 56 core concepts was selected for network analysis.

To evaluate the content validity of the 56 pre-selected concepts and refine them to the core terms necessary for learning "the Components of an Ecosystem" and "the Interactions between Components of an Ecosystem," a review was requested from a panel of five experts: one science education expert and four practicing life science teachers. All participating teachers possessed over 10 years of teaching experience, with two holding master's degrees and two holding doctoral degrees. Concepts that failed to achieve consensus from at least three out of the five experts were eliminated. Consequently, a final set of 45 concepts was established.

Using NetMiner 4.0 software, the learned concept networks formed by students immediately and four weeks after the class were visualized as 1-mode networks based on the final selected concepts. To determine the cognitive significance of specific concepts within the networks for each subtopic, semantic network analysis was conducted using three primary indicators: word frequency, eigenvector centrality, and the total number of links. Word frequency intuitively demonstrates concept importance based on the occurrence count within the network. Eigenvector centrality goes beyond mere connection counts to measure how well a concept is linked to other influential concepts, making it a standard indicator for identifying core concepts (Lee, 2014). The total number of links indicates that students comprehend concepts through interconnected frameworks rather than in isolation, serves as an indicator of deep semantic processing (Collins & Loftus, 1975; Lee, 2014). Crucially, because the sample sizes varied across different levels of science-related attitudes in this study, the normalized indicator of eigenvector centrality was utilized to facilitate rigorous cross-group comparisons. Furthermore, to analyze the inter-subtopic and intra-subtopic differences in students' learned concepts based on their attitude levels immediately and four weeks after the class, interconnected concept networks were visualized as 2-mode networks. Fig. 1 and Fig. 2 illustrate examples of these structures: Fig. 1a displays the 1-mode visualized learned concept network of the upper-level group immediately after the class, while Fig. 2a presents the 2-mode network showing intra-subtopic relationships according to students' levels of science-related attitudes immediately after the class.

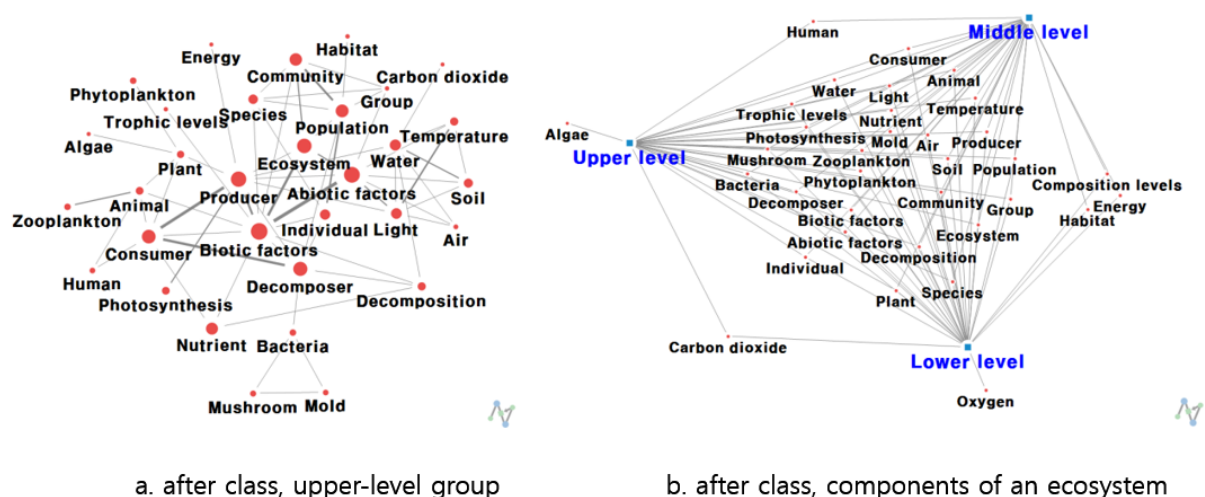
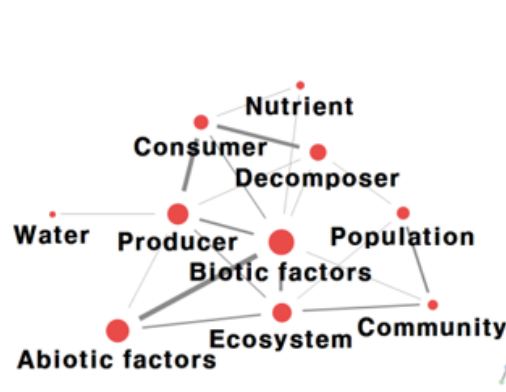
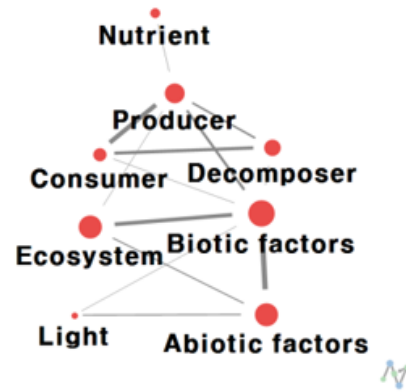


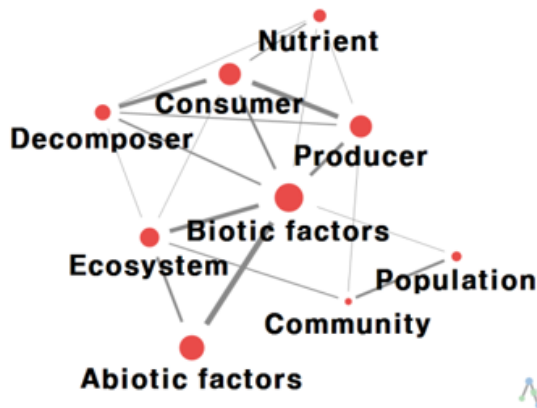
Fig. 1. The example of learned concept networks based on science-related attitudes level for “the Components of an Ecosystem”



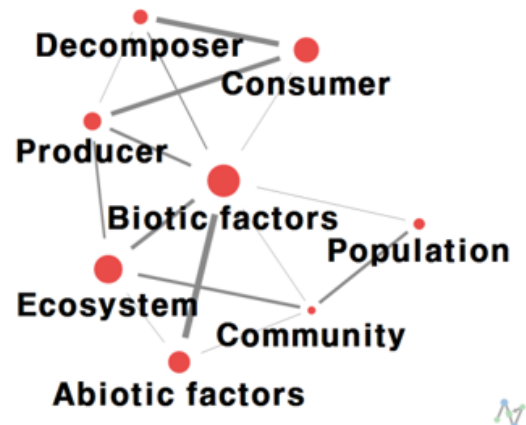
a. after class, upper-level group



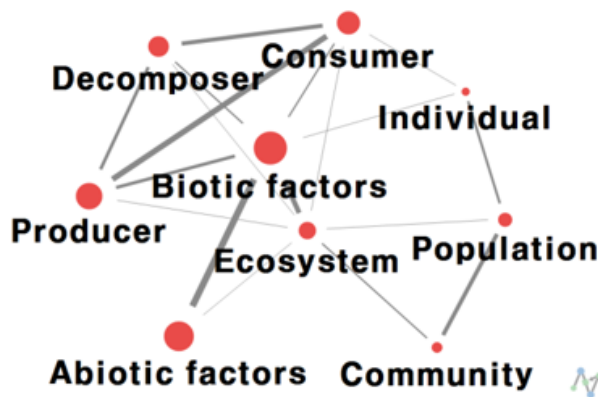
b. four weeks later, upper-level group



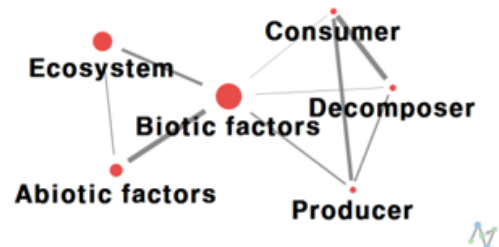
c. after class, middle-level group



d. four weeks later, middle-level group



e. after class, lower-level group



f. four weeks later, lower-level group

Fig. 2. Learned concept networks for “the Components of an Ecosystem” based on science-related attitudes levels

Results

Learned Concept Network

To examine the learned concepts of students immediately and four weeks after the class based on their levels of science-related attitudes, semantic network analysis was conducted. To ensure that the extracted nodes effectively represented the core learned concepts of each group, only the concepts falling within the top 30% in terms of frequency rate were selected for analysis, following the methodology established by Lim et al. (2025).

The Components of an Ecosystem

Fig. 2 illustrates the learned concept networks for “the Components of an Ecosystem” across different levels of science-related attitudes. Immediately after the class, the upper-level group exhibited a network consisting of 10 learned concepts (Fig. 2a). Within this network, the raw word frequencies were ranked in the following order: ‘biotic factors’ (171 times), ‘abiotic factors’ (114 times), ‘producer’ (79 times), ‘ecosystem’ (75 times), and ‘consumer’ (70 times). The eigenvector centrality scores were highest for ‘biotic factors’ (.655), followed by ‘abiotic factors’ (.565), ‘ecosystem’ (.319), ‘producer’ (.295), and ‘consumer’ (.213). This indicates that the network was structured around core concepts characterized by high eigenvector centrality. Specifically, ‘biotic factors’ were connected to trophic-level concepts such as ‘abiotic factors’, ‘producer’, and ‘consumer’, as well as organizational-level concepts including ‘population’ and ‘community’. Meanwhile, ‘abiotic factors’ were structurally linked to ‘biotic factors’, ‘producer’, and the ‘ecosystem’. Four weeks after the class (Fig. 2b), a total of eight concepts remained in the network. The word frequencies were documented in the order of ‘biotic factors’ (79 times), ‘ecosystem’ (51 times), ‘abiotic factors’ (49 times), ‘producer’ (41 times), and ‘decomposer’ (39 times). Although concepts related to trophic levels were continuously retained, those associated with organizational levels were either partially omitted or showed a marked decrease in cross-conceptual links. The eigenvector centrality scores remained highest for ‘biotic factors’ (.672), followed by ‘abiotic factors’ (.590), ‘ecosystem’ (.322), ‘producer’ (.234), and ‘consumer’ (.158), confirming that student learning was sustainably maintained around ‘biotic factors’ and ‘abiotic factors’. Structurally, ‘biotic factors’ were linked to trophic-level concepts such as ‘producer’, ‘consumer’, and ‘decomposer’, as well as ‘light’ and ‘abiotic factors’. Concurrently, ‘abiotic factors’ maintained connections with the ‘ecosystem’, ‘biotic factors’, and ‘light’.

The middle-level group exhibited a network consisting of a total of nine learned concepts immediately after the class (Fig. 2c). Within this network, the raw word frequencies were ranked in the following order: ‘biotic factors’ (255 times), ‘abiotic factors’ (140 times), ‘consumer’ (111 times), ‘ecosystem’ (111 times), and ‘producer’ (111 times). The eigenvector centrality scores were highest for ‘biotic factors’ (.663), followed by ‘abiotic factors’ (.567), ‘ecosystem’ (.285), ‘producer’ (.265), and ‘consumer’ (.245). This indicates that the network was primarily formed around ‘biotic factors’ and ‘abiotic factors’, which were characterized by high eigenvector centrality. Structurally, ‘biotic factors’ were connected to trophic-level concepts such as ‘producer’, ‘nutrient’, and ‘decomposer’, as well as organizational-level concepts including ‘population’. Concurrently, ‘abiotic factors’ were structurally linked to the ‘ecosystem’ and ‘biotic factors’. Four weeks after the class (Fig. 2d), a total of eight concepts remained in the network. The word frequencies were documented in

the order of 'biotic factors' (60 times), the 'ecosystem' (40 times), 'abiotic factors' (37 times), 'consumer' (32 times), and 'producer' (30 times). The eigenvector centrality scores were highest for 'biotic factors' (.590), followed by 'abiotic factors' (.434), 'producer' (.378), and 'consumer' (.357), confirming that the network was sustainably maintained around 'biotic factors' and 'abiotic factors'. Specifically, 'biotic factors' maintained structural connections with trophic-level concepts, including 'producer', 'consumer', and 'decomposer', as well as organizational-level concepts including 'population' and 'community'. Meanwhile, 'abiotic factors' were also structurally linked to the 'ecosystem', 'biotic factors', and 'community'.

The lower-level group exhibited a network consisting of nine learned concepts immediately after the class (Fig. 2e). Within this network, the raw word frequencies were ranked in the following order: 'biotic factors' (119 times), 'abiotic factors' (71 times), 'ecosystem' (54 times), 'producer' (53 times), and 'consumer' (52 times). The eigenvector centrality scores were highest for 'biotic factors' (.666), followed by 'abiotic factors' (.583), 'ecosystem' (.261), 'producer' (.258), and 'consumer' (.217). This demonstrates that the network was structured around 'biotic factors' and 'abiotic factors'. Specifically, 'biotic factors' were connected to trophic-level concepts such as 'producer', 'consumer', and 'decomposer', as well as the 'ecosystem' and 'abiotic factors'. 'Abiotic factors' were structurally linked to 'biotic factors' and the 'ecosystem'. Organizational-level concepts, such as 'population' and 'community', were primarily connected to the 'ecosystem' concept. Four weeks after the class (Fig. 2f), the number of learned concepts dropped to six. The word frequencies were documented in the order of 'biotic factors' (15 times), 'ecosystem' (14 times), 'consumer' (13 times), 'producer' (13 times), and 'abiotic factors' (12 times). However, the eigenvector centrality scores showed a different pattern, ranking in the order of 'consumer' (.532), 'biotic factors' (.437), 'decomposer' (.435), 'producer' (.426), 'abiotic factors' (.308), and 'ecosystem' (.245), confirming a notable decrease in the eigenvector centrality index for 'abiotic factors'. While 'biotic factors' remained connected to trophic-level concepts, organizational-level concepts were entirely omitted from the network. These findings indicate that while 'biotic factors' maintained their central position in the network alongside trophic levels four weeks after the class, the structural connections between 'abiotic factors' and other concepts became relatively weaker in the lower-level group.

Immediately after the class, regardless of students' levels of science-related attitudes, the central hubs of the learned concept networks were consistently characterized by high eigenvector centrality: 'biotic factors', 'abiotic factors', and the 'ecosystem'. Four weeks after the class, however, this central structure was sustainably maintained only within the upper-level group. In contrast, for the middle-level and lower-level groups, only 'biotic factors' retained its central position, while trophic-level concepts such as 'producer' and 'consumer' exhibited an increase in eigenvector centrality, shifting the overall network structure.

Furthermore, immediately after the class, students across all attitude levels structurally differentiated and connected 'biotic factors' into trophic and organizational levels. Yet, four weeks after the class, although trophic-level concepts were continuously retained across all groups, organizational-level concepts were either partially omitted or showed weaker cross-conceptual links. This finding suggests that when teaching 'biotic factors', it is essential to explicitly differentiate between trophic and organizational levels and to repeatedly reinforce organizational-level concepts.

Additionally, immediately after the class, both the upper-level and middle-level groups connected the trophic levels

of ‘biotic factors’ with the concept of ‘nutrient’. However, four weeks after the class, the ‘nutrient’ concept was preserved exclusively within the upper-level group. Notably, the lower-level group failed to present the ‘nutrient’ concept even immediately after the class, revealing a complete disconnect between ‘nutrient’ and trophic-level concepts. Consequently, there is a critical need to deliberately integrate and explain the concept of ‘nutrient’ when introducing trophic levels in the classroom.

Regarding the total number of links between concepts across different levels of science-related attitudes, a decreasing trend was observed from immediately to four weeks after the class: the upper-level group decreased from 19 to 13, the middle-level group from 19 to 15, and the lower-level group from 18 to 9. These findings suggest that students with lower levels of science-related attitudes are relatively more prone to conceptual loss or a conceptual disconnect over time.

The Interactions between Components of an Ecosystem

Fig. 3 illustrates the learned concept networks for “the Interactions between Components of an Ecosystem” across different levels of science-related attitudes. Immediately after the class, the upper-level group exhibited a network consisting of a total of nine learned concepts (Fig. 3a). Within this network, the raw word frequencies were ranked in the following order: ‘biotic factors’ (75 times), ‘light’ (67 times), ‘abiotic factors’ (42 times), ‘plant’ (25 times), and ‘temperature’ (24 times). Among these, ‘biotic factors’ (.679), ‘abiotic factors’ (.629), ‘light’ (.294), ‘wavelength’ (.205), and ‘temperature’ (.100)—which were characterized by high eigenvector centrality—played central roles in the concept network. Structurally, ‘biotic factors’ were connected to concepts such as ‘temperature’, ‘light’, ‘water’, and ‘wavelength’, while ‘abiotic factors’ were structurally linked to ‘biotic factors’ and ‘soil’. Four weeks after the class (Fig. 3b), a total of 10 concepts were presented as learned concepts. The word frequencies were documented in the order of ‘biotic factors’ (48 times), ‘water’ (24 times), ‘light’ (22 times), ‘abiotic factors’ (21 times), and ‘temperature’ (13 times). The eigenvector centrality scores were highest for ‘biotic factors’ (.628), followed by ‘abiotic factors’ (.494), ‘producer’ (.352), ‘decomposer’ (.290), and the ‘ecosystem’ (.173). Specifically, ‘biotic factors’ were connected to trophic-level concepts, including ‘producer’ and ‘decomposer’, as well as ‘temperature’ and ‘water’. Concurrently, ‘abiotic factors’ maintained connections with the ‘ecosystem’, ‘biotic factors’, and ‘light’. These findings suggest that four weeks after the class, the concepts of ‘producer’, ‘consumer’, and ‘decomposer’ related to trophic levels were successfully integrated with the prior concepts regarding ecosystem components learned earlier, establishing robust connections—meaning that meaningful learning occurred—through structural reorganization within the students’ cognitive frameworks.

The middle-level group exhibited a network consisting of eight learned concepts immediately after the class (Fig. 3c). Within this network, the raw word frequencies were ranked in the following order: ‘biotic factors’ (98 times), ‘light’ (96 times), ‘abiotic factors’ (45 times), ‘wavelength’ (41 times), and ‘plant’ (30 times). The network was primarily formed around core concepts characterized by high eigenvector centrality: ‘biotic factors’ (.697), ‘abiotic factors’ (.601), ‘light’ (.360), ‘temperature’ (.100), and ‘wavelength’ (.096). Structurally, ‘biotic factors’ were connected to concepts such as ‘water’, ‘abiotic factors’, and ‘soil’, while ‘abiotic factors’ were structurally linked to ‘biotic factors’, ‘temperature’, and ‘wavelength’. Four weeks after the class (Fig. 3d), a total of eight concepts remained in the network. The word frequencies were documented in the order of ‘biotic factors’ (39 times), the ‘ecosystem’ (34 times), ‘abiotic factors’ (26

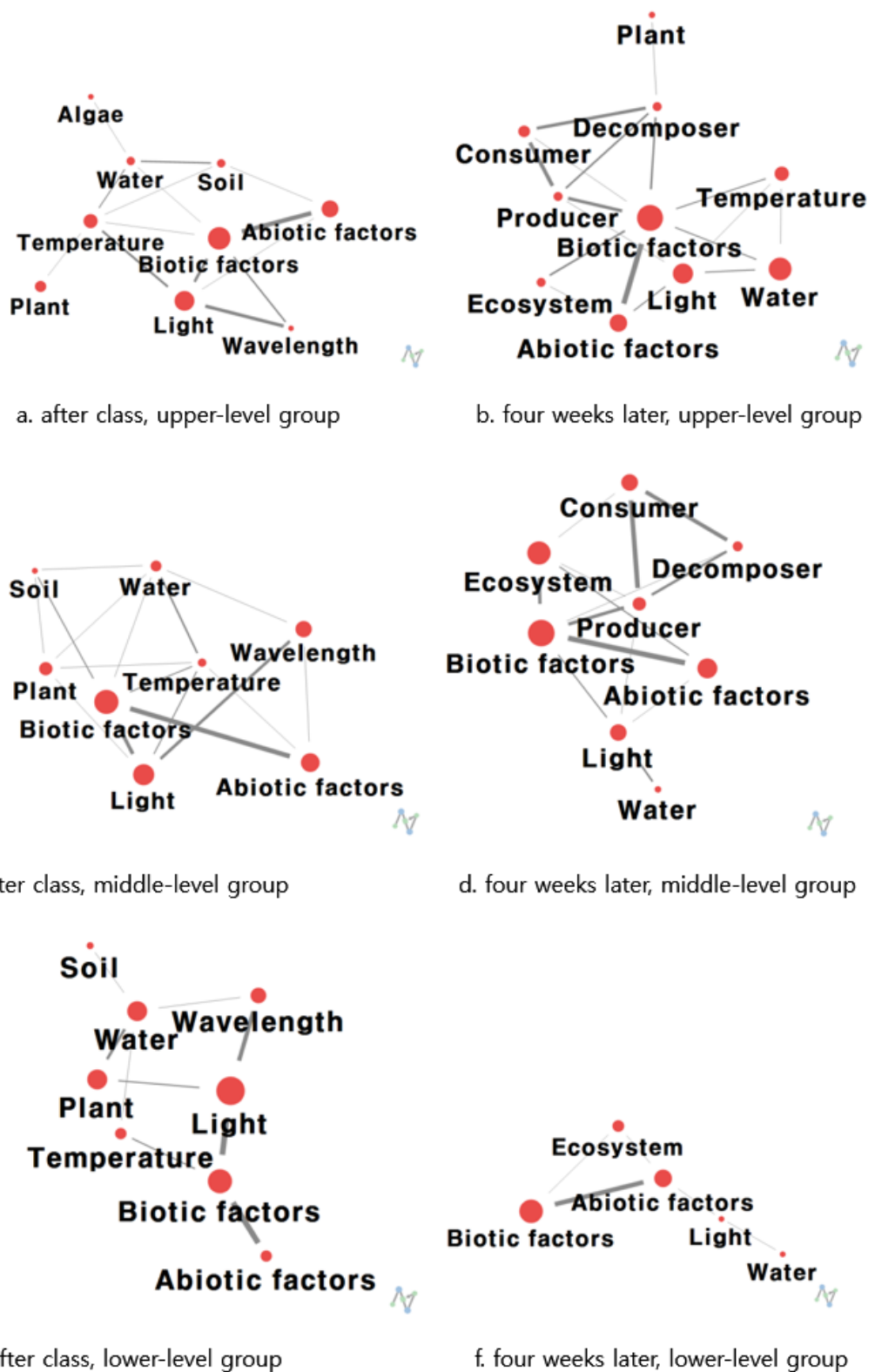


Fig. 3. Learned concept networks for “the Components of an Ecosystem” and “the Interactions between Components of an Ecosystem” based on science-related attitudes level

times), 'consumer' (24 times), and 'light' (23 times). The eigenvector centrality scores were highest for 'biotic factors' (.618), followed by 'abiotic factors' (.540), 'producer' (.366), 'consumer' (.297), and the 'ecosystem' (.228), showing that the network was structured around these specific concepts. These findings suggest that the middle-level group also achieved a restructured cognitive framework, as evidenced by the clear structural connections where trophic-level concepts such as 'producer', 'consumer', and 'decomposer' were successfully linked to 'biotic factors'.

The lower-level group exhibited a network consisting of a total of eight learned concepts immediately after the class (Fig. 3e). Within this network, the raw word frequencies were ranked in the following order: 'light' (45 times), 'biotic factors' (40 times), 'wavelength' (19 times), 'plant' (15 times), and 'abiotic factors' (14 times). The eigenvector centrality scores were highest for 'biotic factors' (.620), followed by 'light' (.571), 'abiotic factors' (.384), 'wavelength' (.304), and 'plant' (.146), showing that the network was formed around these specific concepts. Structurally, 'biotic factors' were connected to concepts such as 'temperature', 'light', and 'abiotic factors', whereas 'abiotic factors' were structurally linked exclusively to 'biotic factors'. Four weeks after the class (Fig. 3f), a total of five concepts were presented in the network. The word frequencies were documented in the order of 'biotic factors' (11 times), 'abiotic factors' (8 times), the 'ecosystem' (5 times), 'light' (4 times), and 'water' (4 times). The eigenvector centrality scores ranked in the order of 'abiotic factors' (.699), 'biotic factors' (.695), the 'ecosystem' (.150), 'light' (.076), and 'water' (.008), with the network being structured around these core hubs. Notably, these findings suggest that within the lower-level group, concepts associated with trophic levels were completely omitted immediately after the class as well as four weeks after the class.

Immediately after the class, regardless of students' levels of science-related attitudes, the central hubs of the learned concept networks were consistently characterized by concepts with high eigenvector centrality, such as 'biotic factors', 'abiotic factors', 'light', 'wavelength', and 'temperature'. Four weeks after the class, however, a meaningful shift in the central structures occurred within the upper-level and middle-level groups; this rearrangement was driven by the integration of trophic-level concepts from the previous class block—such as 'producer', 'consumer', and 'decomposer'—which subsequently exhibited an increase in eigenvector centrality. In contrast, the lower-level group completely failed to present these prior concepts four weeks after the class.

These findings suggest that students in the upper-level and middle-level groups successfully restructured their cognitive frameworks four weeks after the class by bridging the new concepts from "the Interactions between Components of an Ecosystem" with the trophic-level concepts previously acquired in "the Components of an Ecosystem." Conversely, although the lower-level group demonstrated a conceptual awareness similar to that of the higher groups immediately after the class, they omitted most of the immediate-recall concepts four weeks later. Furthermore, they were unable to either retrieve or connect the concepts learned in the preceding lesson block. This phenomenon suggests that students with lower levels of science-related attitudes tend to acquire concepts segmentally and superficially within individual lesson blocks rather than establishing unified knowledge structures.

Regarding the total number of links between concepts across different levels of science-related attitudes, variations were observed from immediately to four weeks after the class: the upper-level group increased from 14 to 18, the middle-level group decreased from 16 to 14, and the lower-level group decreased from 9 to 5. These results suggest that students with lower levels of science-related attitudes not only face greater difficulties in cognitive retention and recall of learned

concepts over time but also experience a pronounced reduction in cross-conceptual connectivity.

Connection Concept Network

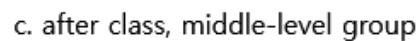
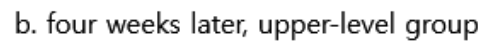
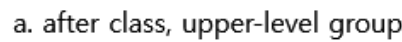
To facilitate a comprehensive comparison of students' learned concepts based on their levels of science-related attitudes, the interconnected concept networks showing both inter-subtopic and intra-subtopic relationships were analyzed immediately and four weeks after the class. Furthermore, the variations in the learned concepts within and between these subtopics across different levels of science-related attitudes were visualized through these specialized 2-mode networks.

Inter-subtopic Connection Concept Networks

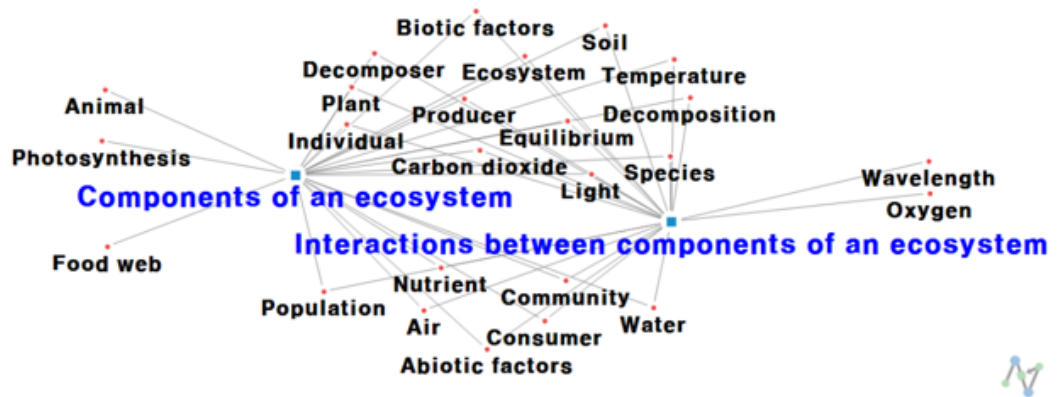
Immediately after the class, the upper-level group concurrently learned 19 concepts—including 'animal', 'photosynthesis', 'decomposer', the 'ecosystem', and 'bacteria'—inter-subtopic wise between “the Components of an Ecosystem” and “the Interactions between Components of an Ecosystem” (Fig. 4a). The concepts learned exclusively within “the Components of an Ecosystem” subtopic consisted of 13 terms, such as 'phytoplankton', 'zooplankton', and 'community'. Meanwhile, six concepts, including 'poikilotherm', 'adaptation', and 'reproduction', were acquired solely within “the Interactions between Components of an Ecosystem” subtopic. Four weeks after the class (Fig. 4b), the group integrated a total of 21 concepts—such as 'photosynthesis', 'nutrient', 'plant', 'abiotic factors', and 'soil'—bridging both subtopics together. Concepts like 'species', 'air', 'population', 'mold', and 'community' were retained exclusively within “the Components of an Ecosystem” subtopic. Conversely, six concepts—including 'carbon dioxide', 'fox', 'body temperature', 'equilibrium', 'habitat', and 'human'—were learned only within “the Interactions between Components of an Ecosystem” subtopic.

For the middle-level group, a total of 16 concepts—including 'animal', 'producer', 'decomposer', 'consumer', and 'light'—were learned across both subtopics immediately after the class (Fig. 4c). Fourteen concepts, such as 'composition levels', 'bacteria', 'group', 'community', and 'mold', were learned exclusively within “the Components of an Ecosystem” subtopic, whereas 'adaptation', 'body temperature', 'algae', 'reproduction', and 'habitat' were restricted solely to “the Interactions between Components of an Ecosystem” subtopic. Four weeks after the class (Fig. 4d), the number of cross-subtopic integrated concepts increased to 20, including 'consumer', 'species', 'carbon dioxide', 'light', and 'biotic factors'. During this retention phase, 'animal', 'photosynthesis', and 'food web' were found exclusively in “the Components of an Ecosystem” subtopic, while 'wavelength' and 'oxygen' were mapped only within “the Interactions between Components of an Ecosystem” subtopic.

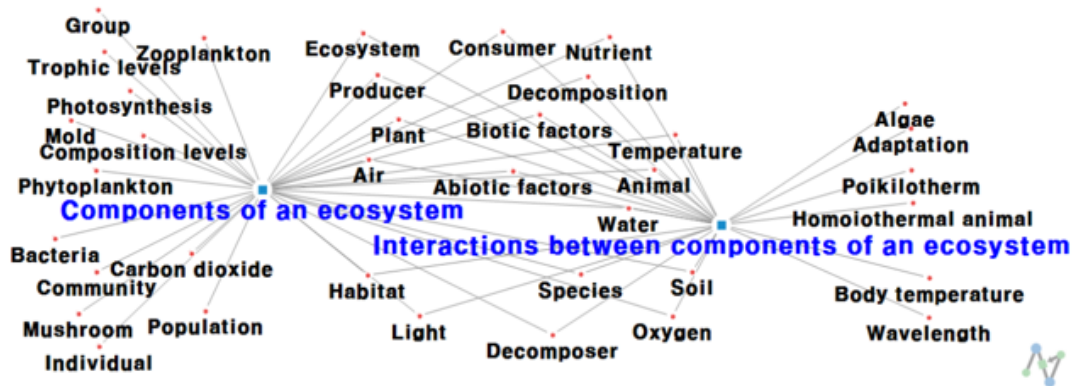
In contrast, the lower-level group showed 18 concepts—such as the 'ecosystem', 'consumer', 'nutrient', 'air', and 'decomposition'—bridging the two subtopics immediately after the class (Fig. 4e). Thirteen concepts, including 'trophic levels', 'photosynthesis', 'mold', and 'composition levels', were isolated within “the Components of an Ecosystem” subtopic. Additionally, six concepts—'algae', 'adaptation', 'poikilotherm', 'body temperature', 'homoiothermal animal', and 'wavelength'—were uniquely learned within “the Interactions between Components of an Ecosystem” subtopic. Four weeks after the class (Fig. 4f), the number of concepts integrating both subtopics sharply dropped to 11, which included the 'ecosystem', 'consumer', 'decomposer', and 'producer'. Six concepts, such as 'plant', 'decomposition',



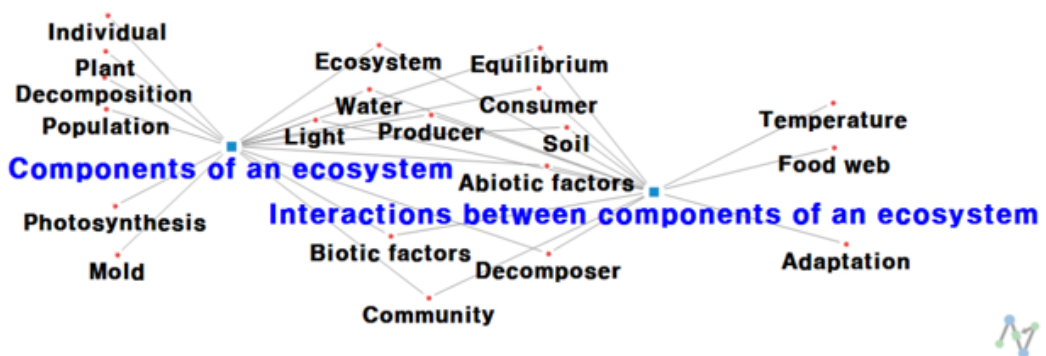
268



d. four weeks later, middle-level group



e. after class, lower-level group



f. four weeks later, lower-level group

Fig. 4. Inter-subtopic connection concept networks (continued)

‘population’, and ‘individual’, were retained only in “the Components of an Ecosystem” subtopic, while a mere three concepts—‘temperature’, ‘food web’, and ‘adaptation’—remained exclusively within “the Interactions between Components of an Ecosystem” subtopic.

From immediately to four weeks after the class, the total number of inter-subtopic connecting concepts increased from 19 to 21 for the upper-level group and from 16 to 20 for the middle-level group; however, it markedly decreased from 18 to 11 for the lower-level group. These findings suggest that students with higher levels of science-related attitudes demonstrate a stronger cognitive tendency to structurally anchor and cross-link newly acquired concepts with their prior conceptual foundations.

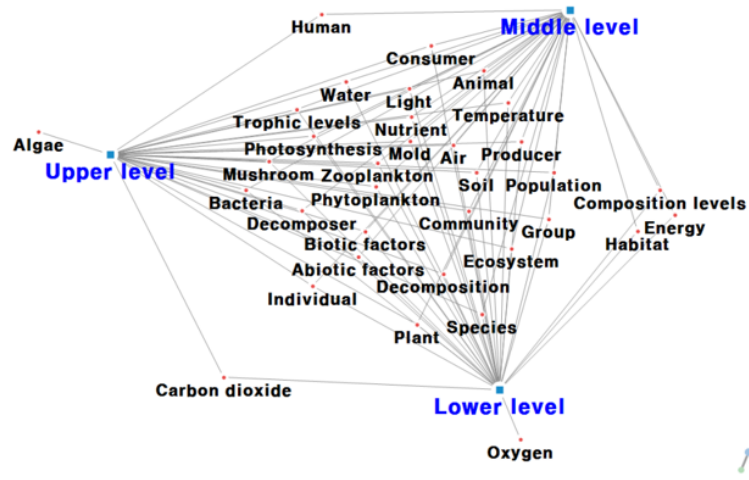
Intra-subtopic Connection Concept Networks

Fig. 5 illustrates the intra-subtopic interconnected concept networks according to students’ levels of science-related attitudes immediately and four weeks after the class. Immediately after the class for “the Components of an Ecosystem” subtopic (Fig. 5a), a total of 27 concepts—including ‘trophic levels’, ‘water’, ‘light’, ‘animal’, ‘nutrient’, and ‘temperature’—were commonly shared across all groups regardless of their science-related attitude levels. Structurally, the upper-level and middle-level groups shared the concept of ‘human’; the upper-level and lower-level groups shared ‘carbon dioxide’; and the middle-level and lower-level groups shared ‘composition levels’, ‘energy’, and ‘habitat’. Notably, these findings suggest that the upper-level group uniquely retained the concept of ‘algae’, whereas the lower-level group individually presented the concept of ‘oxygen’.

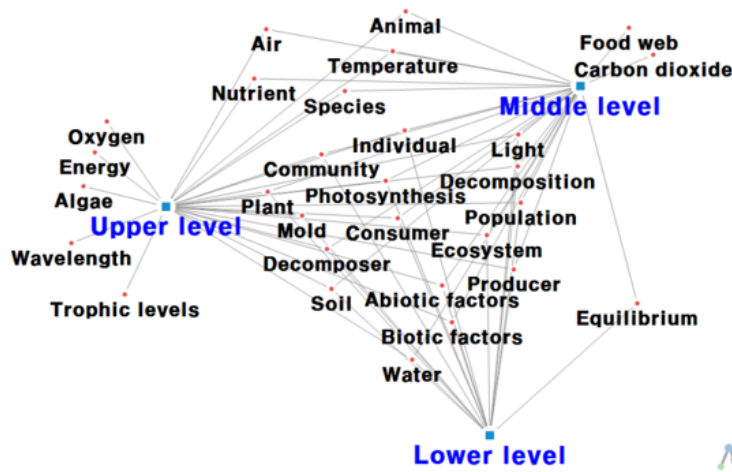
Four weeks after the class for “the Components of an Ecosystem” subtopic (Fig. 5b), 16 concepts—such as ‘community’, ‘light’, ‘individual’, ‘decomposition’, and ‘consumer’—were shared across all science-related attitude levels. The upper-level and middle-level groups shared the concepts of ‘air’, ‘animal’, ‘nutrient’, ‘temperature’, and ‘species’, while the middle-level and lower-level groups shared ‘equilibrium’. In addition, the upper-level group supplementally presented concepts such as ‘oxygen’, ‘energy’, ‘algae’, ‘wavelength’, and ‘trophic levels’, whereas the middle-level group additionally retained ‘food web’ and ‘carbon dioxide’.

Immediately after the class for “the Interactions between Components of an Ecosystem” subtopic (Fig. 5c), 22 concepts—including the ‘ecosystem’, ‘consumer’, ‘producer’, ‘abiotic factors’, and ‘biotic factors’—were commonly generated by students across all attitude levels. The upper-level and middle-level groups shared the concept of ‘reproduction’, while the upper-level and lower-level groups shared ‘adaptation’. Furthermore, the upper-level group exclusively presented ‘bacteria’, ‘photosynthesis’, and ‘metabolism’; the middle-level group uniquely presented ‘human’; and the lower-level group supplementally produced ‘oxygen’ and ‘species’.

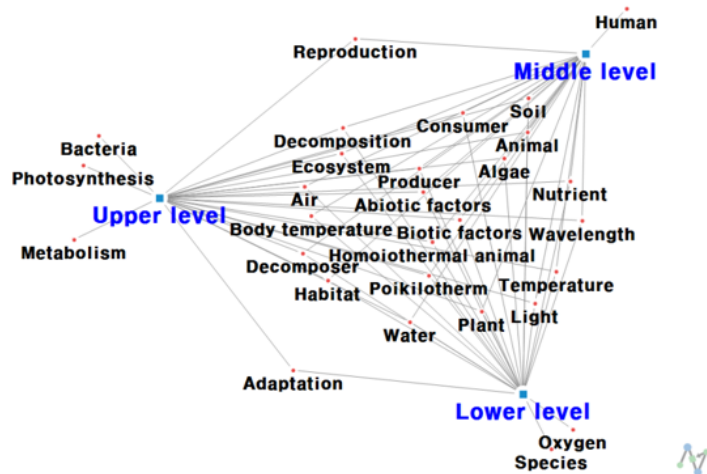
Four weeks after the class for “the Interactions between Components of an Ecosystem” subtopic (Fig. 5d), 11 concepts—such as the ‘ecosystem’, ‘abiotic factors’, ‘biotic factors’, ‘consumer’, ‘producer’, and ‘decomposer’—were successfully retained by all students across all attitude levels. The upper-level and middle-level groups shared seven concepts, including ‘plant’, ‘nutrient’, ‘oxygen’, and ‘decomposition’, while the middle-level and lower-level groups shared ‘community’. Beyond these shared nodes, these results suggest that the upper-level group continuously retrieved 10 additional concepts, such as ‘body temperature’, ‘trophic levels’, ‘energy’, and ‘photosynthesis’. Concurrently, the



a. after class, the components of an ecosystem

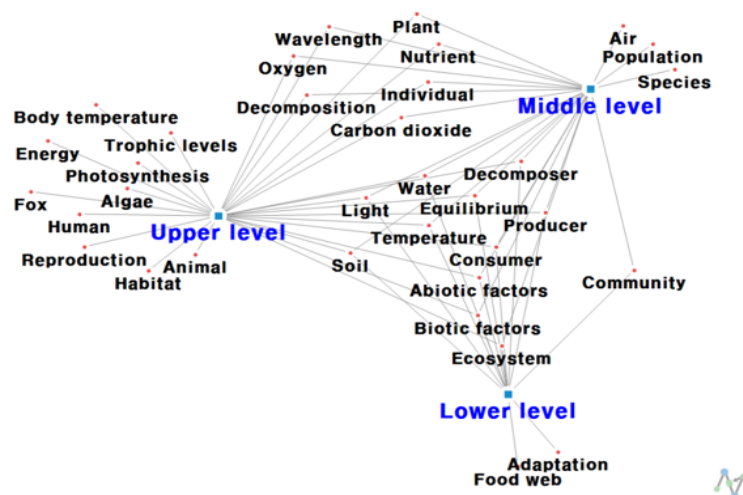


b. four weeks later, the components of an ecosystem



c. after class, the interactions between components of an ecosystem

Fig. 5. Intra-subtopic connection concept networks



d. four weeks later, the interactions between components of an ecosystem

Fig. 5. Intra-subtopic connection concept networks (continued)

middle-level group supplementally presented ‘air’, ‘population’, and ‘species’, whereas the lower-level group uniquely provided ‘food web’ and ‘adaptation’.

Immediately after the class, the number of concepts commonly presented by students was higher than that observed four weeks after the class, regardless of their levels of science-related attitudes. Four weeks after the class, however, there was a pronounced increase in the number of concepts retained exclusively by the upper-level and middle-level groups, as well as those recalled solely by the upper-level group. These findings suggest that students with higher levels of science-related attitudes demonstrate a stronger cognitive capability to retain and present a greater number of learned concepts over time.

Discussion

This study analyzed the variations in science learning according to 10th-grade students’ levels of science-related attitudes through the utilization of semantic network analysis. To achieve this, the learned concept networks alongside the inter-subtopic and intra-subtopic connection concept networks were examined, focusing on the instruction of “the Components of an Ecosystem” and “the Interactions between Components of an Ecosystem.” Regardless of their science-related attitude levels, students mapped their conceptual networks around similar foundational hubs—such as the ‘ecosystem’, ‘biotic factors’, and ‘abiotic factors’—differing primarily in the overall network structures. This alignment is consistent with previous literature investigating post-instruction concept networks in relation to cognitive structure levels (Lim et al., 2024) and academic achievement in science (Kim et al., 2026). Furthermore, when connected to prior research indicating that a failure to accurately comprehend the interrelatedness among concepts leads to significant learning difficulties (Dole, 2003; Knippels et al., 2005), these findings suggest that the structural differences in learned concept networks driven by variations in science-related attitudes can function as a critical determinant of final

learning outcomes.

Variations were observed in the number of concepts presented by students over time, according to their levels of science-related attitudes. When comparing the number of nodes between immediately and four weeks after the class, the upper-level and middle-level groups exhibited a significantly smaller decrease in retained concepts compared to the lower-level group. These findings suggest a strong alignment with Bodas and Kelemen (2026), who reported that a higher level of science-related attitudes correlates with a greater volume of retained scientific concepts, as well as Lim and Oh (2004), who demonstrated that positive emotional dispositions toward science enhance long-term cognitive retention.

Furthermore, the upper-level group consistently maintained around 20 interconnected concepts across both inter-subtopic domains (“the Components of an Ecosystem” and “the Interactions between Components of an Ecosystem”) both immediately and four weeks later; conversely, the lower-level group displayed a stark contraction in cross-subtopic connectivity, plummeting from 18 to 11 concepts (Fig. 4). Additionally, the upper-level group successfully connected the trophic levels of ‘biotic factors’ with the concept of ‘nutrient’ immediately after the class (Fig. 2), whereas the lower-level group failed to do so. Even four weeks after the class, the upper-level group sustainably bridged ‘nutrient’ with trophic-level pathways, while the nutrient concept was entirely omitted in the middle-level and lower-level groups, resulting in a conceptual disconnect. This contrast aligns with Schunk (2012), who noted that a positive attitude toward a discipline stimulates autonomous cognitive efforts to link new information with prior knowledge structures. The omission of such critical core concepts or the degradation of cross-conceptual connectivity can heavily compromise final academic achievement (Lim, 2019).

On the other hand, regardless of attitude levels, all students initially conceptualized ‘biotic factors’ by clearly distinguishing between trophic and organizational levels immediately after the class (Fig. 2). After four weeks, however, only the middle-level group preserved this structural distinction, while the remaining groups retained only the trophic-level components. This pattern implies that prior knowledge elements introduced in previous school levels—such as ‘producer’, ‘consumer’, and ‘decomposer’—gained time to think back through new instructional experiences, which in turn generated a cognitive facilitation effect (Garlitch & Wahlheim, 2020; Negley et al., 2018). In contrast, the newly introduced connection between ‘nutrient’ and trophic dimensions, alongside organizational levels like ‘population’ and ‘community’, failed to trigger equivalent reinforcement.

Moreover, students in the lower-level group left relational paths between key concepts ambiguous. For instance, four weeks after the class for “the Interactions between Components of an Ecosystem,” they failed to map structural connections between abiotic factors (such as ‘light’ and ‘water’) and ‘biotic factors’ (Fig. 3), failing to achieve a stable understanding of the curricular material.

Interestingly, unlike the upper-level group, the middle-level and lower-level groups four weeks after the class cross-linked contents from distinct class blocks inappropriately. In the learned concept network for “the Components of an Ecosystem,” the middle-level group mapped ‘food web’ and ‘equilibrium’, while the lower-level group mapped ‘equilibrium’ onto the structural components of an ecosystem (Fig. 4). Similarly, within “the Interactions between Components of an Ecosystem,” the middle-level group recalled ‘equilibrium’, and the lower-level group integrated

‘food web’ and ‘equilibrium’ into the interaction network. These results suggest that science-related attitudes dictate the capability to systematically compartmentalize and integrate targeted academic themes.

In conclusion, lower science-related attitudes directly undermine students’ ability to consistently retrieve or systematically link relevant scientific constructs over time. Furthermore, due to a lack of conceptual boundaries between separate learning modules, these students prone to misconnecting subsequent learning elements back onto prior foundations. Ultimately, these insights suggest that these structural deficiencies serve as a primary underlying mechanism driving the well-documented achievement gaps in science education (Freedman, 1997; Lee & Chung, 2014; Simpson & Oliver, 1990).

Conclusions and Implications

This study analyzed the learned concept networks alongside the inter-subtopic and intra-subtopic connection concept networks according to 10th-grade students’ levels of science-related attitudes regarding ecosystem configurations. To achieve this, the target unit was categorized into “the Components of an Ecosystem” and “the Interactions between Components of an Ecosystem” and visualized through network structures. The conclusions of this study are as follows:

First, students focused their learning on specific concepts immediately after the class, regardless of the individual lesson blocks. Across all levels of science-related attitudes, students constructed networks centered primarily around ‘biotic factors’ and ‘abiotic factors’. Although they anchored their understanding on these identical core concepts, the actual architecture of their learned concept networks—specifically the structure of cross-conceptual connectivity—differed depending on their science-related attitude levels.

Second, there was a pronounced difference in the degree to which students recalled learned concepts based on their attitude levels. In the lower-level group, concepts regarding the organizational levels of ‘biotic factors’ were completely omitted four weeks after the class. Consequently, four weeks after the class, the number of concepts they successfully retained was small, and their network topologies became heavily simplified. These findings suggest that a lower level of science-related attitudes not only leads to a decline in the number of retained concepts over time but also renders the overall network structure highly vulnerable to simplification. In other words, students with lower science-related attitudes experience weaker conceptual recall and tend to acquire concepts in isolation, demonstrating a deficient degree of cross-conceptual connectivity.

Third, students in the lower-level group were more susceptible to the confounding effects of subsequent learning elements. While the upper-level and middle-level groups successfully restructured their cognitive frameworks by linking prior and subsequent learning components, the lower-level group failed to do so. Accordingly, students with lower science-related attitudes faced severe difficulties not only in continuously retrieving concepts from prior lessons but also in establishing connectivity between them. This phenomenon implies that when learning is not sustainably maintained, students rely disproportionately on recency effects, recalling concepts that are chronologically closer to the present testing phase more intensely. Notably, the concepts of ‘food web’ and ‘equilibrium’—which are formally introduced in subsequent instructional sessions—emerged in a cross-linked fashion exclusively within the networks of the middle-

level and lower-level groups.

Over time, lower science-related attitudes result in a stark contraction in the number of recalled scientific concepts and a systematic failure to link these concepts relationally. Under these conditions, newly introduced subsequent learning concepts exert an overwhelming influence on the architecture of prior knowledge structures. Therefore, to scaffold the conceptual learning of the lower-level group, core topics must be clustered and presented in a 'chunk form' to facilitate smoother cross-conceptual integration, and these clusters must be repeatedly reinforced. Furthermore, classroom instruction should clearly separate the domains of prior and subsequent learning modules, prioritizing a highly explicit presentation of the interrelationships among scientific concepts.

This study sought to analyze structural differences in concept networks driven by science-related attitudes. However, because this investigation relied on a cross-sectional comparison between distinct groups, establishing a definitive causal relationship between the two target variables remains a limitation. Consequently, it is expected that future research will more clearly verify these variations by rigorously controlling for other confounding factors that heavily dictate network formation, such as students' science achievement, learning motivation, and teacher-related variables.

Conflicts of Interest

The authors declared no conflicts of interest.

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