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An Analysis of Education Implementation for the Improvement of Education for Sustainable Development (ESD) of Pre-service Science Teachers: Focusing on the Integration of Sustainable Happiness and Complexity Theory – A Secondary Publication

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Abstract: In this study, class demonstrations conducted integrating science education and 'Education for Sustainable Development (ESD)' by preservice science teachers were analyzed, focusing on the concept of 'sustainable happiness' and the main elements of 'complexity theory.' In addition, changes before and after participating in such education implementation were analyzed from various angles. Through this, preservice science teachers tried to derive implications for developing multidimensional teacher professionalism in ESD. The main findings are as follows. First, as a result of peer evaluation of class materials and class demonstrations designed by preservice science teachers, the average of the integration for 'sustainable happiness' was relatively high. Next, it was analyzed that the elements of 'sustainable happiness' and 'complexity theory' generally had a positive correlation with ESD. In addition, after participating in the study, preservice science teachers considered individual and social behavioral patterns as important in the sense of ESD. Regarding the need to integrate science education and ESD, preservice science teachers thought it was necessary to deal with the concept of 'sustainable happiness' in science education to understand a sustainable way of life. It was analyzed that the elements of 'sustainable happiness' and 'complexity theory' generally had a positive correlation with ESD. It was found that preservice science teachers' confidence in incorporating ESD in science classes was significantly higher after participation in the study. In addition, it was analyzed that preservice science teachers have come to think more about the role of teachers who can communicate with students and think about happy lives together than before. Overall, it is thought that preservice science teachers have come to think of multidimensional science teacher professionalism by applying the perspective of the teaching and learning strategy of the new ESD, which integrates the concept of 'sustainable happiness' and elements of 'complexity theory.'

Keywords: Preservice science teachers; Education implementation; Education for Sustainable Development (ESD); Sustainable happiness; Complexity theory

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1. Introduction

Education for sustainable development (ESD) can be defined as "education necessary to improve the lives of current and future generations" and "education that seeks to promote a society that pursues values, behaviors, and ways of life necessary for sustainable future and social transformation" [1,2].

ESD in schools can be integrated in various ways depending on the goals of the classes. Some representative integration methods include a balanced approach to the three areas of society, environment, and economy, where students can identify conflicts within the social system and work towards resolving these conflicts by finding a balance point among society, environment, and economy [3-5]. Additionally, there is an approach to ESD related to the 17 SDGs (Sustainable Development Goals) that address universal human issues, global environmental issues, and economic and social issues [6].

In addition to the above approaches, there is an effort to integrate the concept of sustainable happiness, which explores the relationship between human happiness and sustainability, into ESD. While sustainable development and ESD have mainly focused on development theories, policies, and paradigm shifts [7], there is now a need to explore ways to pursue sustainable happiness that connect the present and the future by inducing an understanding of the difference between unsustainable happiness and sustainable happiness.

O'Brien [7] first defined sustainable happiness as the happiness that contributes to individual, community, and global well-being without harming others, the environment, and future generations. This emphasizes the interdependence of all life forms on Earth and the fact that each of us can positively or negatively contribute to the well-being of others and the natural environment.

Happiness and sustainable living are interconnected, and sustainable living is associated with a good life. For example, when feeling happy while drinking coffee, it's not just about drinking coffee but it can be sustainable happiness when seeking or consuming fair-trade coffee. In other words, when striving to find the intersection between happiness and sustainability, sustainable happiness can be felt [8].

Recently, in ESD, the focus has been on minimizing anthropocentric perspectives and emphasizing the relationship, coexistence, and sustainability of nature and humanity [9]. Therefore, it can be said that ecological thinking based on an ecological worldview, which clarifies the relationship between social issues and education, underscores the importance of ecological thinking and educational practices. The social issues arising in the social system form complex system structures as various factors interact. The variables involved in addressing social issues in ESD are becoming increasingly diverse, and the situational constraints are strengthening, with the variability of problems changing rapidly over time [10]. In this regard, integrating complexity theory into ESD can be a highly effective educational strategy.

Knowledge in complexity theory refers to the formation of self-existence, which involves exploring and participating in the surrounding environment, community, and society to examine how one's existence is manifested within them [11-14]. Thus, the most crucial aspect of integrating complexity theory into education lies in how learners engage with the surrounding world. For example, in climate change education, the emphasis should be on understanding the interrelatedness of various elements of the Earth. To achieve this, we need to critically and insightfully contemplate questions such as: How are we related to ourselves, others, nature, society, and the global community? Through such critical and insightful reflections, humans can understand that they are part of the natural world, organisms, individuals, members of society and culture, and also unique individuals [15].

As seen above, when considering the effectiveness of ESD, integrating the concept of sustainable happiness and elements addressed in complexity theory can be a highly useful strategy. Moreover, considering the recent revisions in the 2022 revised curriculum [16], which includes fostering the core competency of "a creative person who creates new values through progressive thinking and challenges on the basis of broad-based knowledge and abilities," and core capacities such as "aesthetic sensitivity competence, reflecting on and enjoying the meaning and value of life based on empathetic understanding and sensibility towards the diversity of human life and culture," and "community competence, actively and responsibly participating in sustainable global community development with open and inclusive values and attitudes demanded by local, national, and global communities," it is urgent for prospective science teachers to cultivate expertise in ESD based on relational engagement.

Therefore, in this study, we aim to analyze ESD teaching materials and demonstrations designed by prospective science teachers by integrating key elements of sustainable happiness and complexity theory and to derive implications for enhancing multidimensional teacher professionalism in science education integrated with ESD by analyzing perception changes before and after participating in such educational practices.

2. Theoretical background

2.1. Sustainable happiness

Brown & Kasser stated that "deciding how to act on an individual level when environmentally responsible behavior is perceived as self-sacrificing can be a difficult choice" [17]. This is because environmentally responsible behavior can be assumed to undermine personal happiness. Sustainable happiness offers a new approach that provides opportunities to reflect on sustainability issues and improve the quality of our lives, contributing to individual, local, and global well-being.

In the OECD Education 2030 report, "Future of Education and Competencies," the role of education is set to focus on all learners becoming holistic individuals, maximizing their potential, and striving to create a shared future based on individual and collective well-being, and the well-being of the planet [18]. The core goal outlined by the OECD Compass for Learning is described as "learners embarking on a journey toward Well-being 2030 with a compass in hand, supported and collaborating with peers, teachers, and communities."

In future education, the theme of "happiness" is prominently addressed. True happiness arises not from material possessions but from meaningful events happening around us, and participation in local community activities, and individuals with less materialistic tendencies tend to have higher self-reports of happiness and engage more in environmentally friendly activities [19,20].

Despite individual happiness being recognized as a significant goal in education, it has traditionally been pursued through informal or non-formal education. However, Noddings argued that happiness should be a specific aim of education, stating that good education should support individual and group-level happiness [21]. It is argued that sustainable happiness should be integrated into each curriculum so that learners understand the relationship between happiness and sustainability [22].

De Young confirmed through research that pro-social behaviors such as environmental actions and community engagement can enhance personal well-being [23], while Myers and Diener confirmed that factors influencing life satisfaction are fundamentally non-materialistic [24]. The values individuals hold have significant psychological implications for motivation and personal well-being [17]. According to Kasser and Ryan [25], individuals with intrinsic values have a higher perception of personal well-being compared to those with extrinsic values. Additionally, research by Richin and Dawson found that individuals oriented towards materialism have lower subjective well-being and engage less in environmentally friendly activities than those with lower materialism [26]. This indicates that pursuing intrinsic values can promote both subjective well-being and ecologically responsible behavior.

To apply the concept of sustainable happiness in classrooms, reflective and transformative teaching methods are required. Sustainability concerns the entire Earth and should be considered in all aspects of life [27]. To achieve this, prospective teachers need to cultivate teaching professionalism that enables learners to reflect on their values and develop the capacity to participate in creating a better society [28].

The UNESCO 2050 report, "Our Shared Future: A New Social Contract for Education," containing the future vision of education, emphasizes that curricula should allow learners to access shared knowledge. It suggests that curricula should move away from the narrow framework of transmitting facts and information to learners actively applying and generating knowledge, and should be structured to allow for the repositioning of humanity in a rapidly changing world [29]. As emphasized in this report, education is not only a public good provided to everyone but also a common good co-created through societal participation and efforts. Therefore, the purpose, content, and processes of education can be closely integrated with the concept of sustainable happiness.

2.2. Complexity theory

The social issues raised in education for sustainable development are inherently multidimensional, and effective approaches to seeking solutions involve stimulating learners' interest through interdisciplinary approaches and engaging them in social participation and practical activities that shape their values [30,31]. These characteristics of education for sustainable development are closely related to three key concepts of complexity theory (self-organization, emergence, fractals). First, the concept of "self-organization" refers to learners exploring their existence by deeply engaging with the environment, communities, and society, understanding how they relate to the world around them. Activities that involve continuously adapting oneself to changes in the surrounding environment through self-organization can be considered important educational goals from a complexity perspective [11-14]. Recently, education for sustainable development has emphasized the importance of learners reflecting on their values and inducing changes in values for sustainable living through personal reflection. This can be clearly achieved through communication and decision-making processes with peer students in class, actively engaging in practical activities for sustainable societies with sensitivity to their local communities, thus confirming their role in real-world changes and restoring their self-identity through educational outcomes.

This perspective is also central to Dewey's educational curriculum theory, which emphasizes the need for teachers to tailor the logical structure of the curriculum to students and emphasizes that "knowing" does not directly lead to "behavioral change" [32,33]. This well reflects the vision of education for sustainable development as a synthesis of "logic and emotion" [34].

Next, another concept addressed in complexity theory, "emergence," refers to the discovery of new and consistent structures, properties, patterns, etc., resulting from increased complexity in the relationships between elements [12,35]. Mikulecky distinguished two types of emergence: one where unexpected new things suddenly emerge in the process of evolution, and the other where the characteristics of phenomena that were not visible before are discovered [36]. These two processes of emergence, interrelated causally, are closely related to the competency of systemic thinking emphasized in education for sustainable development. Systemic thinking can be defined as the ability to think about the world in interconnected, causal, cyclical, emergent, and holistic perspectives [37].

From the perspective of emergence, classes are perceived as processes of interaction among learners, and these interactions among learners themselves become self-directed [38]. Even in classroom settings where education for sustainable development is taking place, students become involved in complex and dynamic networks of interaction as they explore issues related to their studies. This process can be predictable or unpredictable. Students may also experience a sense of achievement in suddenly discovering something new through dynamic communication with their peers.

In such classrooms, rather than moving toward a single instructional goal, students will simultaneously possess autonomy and responsibility to find meaningful instructional goals during the course, enabling them to comprehensively understand various perspectives existing in society. Here, learning becomes a process of transformation where students engage in particular possibilities and paths, rather than acquiring external knowledge. Furthermore, learning becomes a process of iterative trial and error rather than accumulation [39].

Finally, the "fractal" structure applied in complexity theory refers to a geometric shape whose detailed pattern remains the same even when it is reduced or enlarged. Fractal images are created through a recursive and iterative process, where the output of the previous stage becomes the input of the next stage, indicating the characteristics of preserving the "content and context" of the previous stage. It is inappropriate to express the structure of knowledge and learning as closed areas such as straight lines or plane geometry. Rather, it is more appropriate to describe it using concepts such as recursion, iteration, and feedback loops [14]. Fractal images can be utilized as a tool for developing and implementing learner-centered educational programs through the process of emergence. For example, the image of a tree branching out into another branch can be useful in describing the image of the "emergent space." That is, a network structure that expands from small nodes to large nodes can be utilized not only to explain the knowledge production system but also to describe the produced knowledge system [13]. Kiraly has applied fractal elements when operating group projects in the classroom [40]. First, he mentioned "collaborative emergence," where students dynamically interact with peer students, teachers, local experts, etc., forming a learning community and growing themselves. Second, "self-similarity" is reflected in group projects where students have opportunities to iteratively repeat processes such as project selection, organization, and execution.

These characteristics can serve as a fundamental direction for developing educational models for education for sustainable development. That is, to solve problems arising in society, it is important to find a balance between society, environment, and economy while resolving conflicts. This can be proposed as a fractal structure. For this "relation-oriented education for sustainable development," it is important to view it as continuous interactions between social, environmental, and economic domains, and these processes can be applied using the fractal image of complexity theory.

3. Research methodology and procedures

3.1. Research participants and course delivery

The participants of this study were 21 pre-service science teachers attending the "Education for Sustainable Development and Science Education" course at the College of Education, A University, located in the metropolitan area. Among them, there was one student in the second year, 17 students in the third year, and three students in the fourth year. Regarding their enrollment status in science education-related courses, second-year students took one course, while third and fourth-year students took three or more courses related to science education (such as Integrated Science Education Theory, Integrated Science Education Curriculum and Instructional Methods, Practical Science Inquiry, etc.).

For this study, the delivery of the "Education for Sustainable Development and Science Education" course proceeded in four main stages. Firstly, in the first stage of the course, before participating in the classes, pre-service teachers were asked to write a pre-opinion sheet regarding topics such as their teacher orientation, the meaning of education for sustainable development, the necessity of integrating education for sustainable development into science education, and their confidence in integrating education for sustainable development into middle school science education. Some of the questions from the pre-opinion sheet were also included in the post-reflection sheet, which was completed after completing all 15 weeks of the course, to analyze changes in the thinking of pre-service teachers after completing the course. Furthermore, various multidimensional characteristics were discussed during the course, focusing on different approaches such as integration centered on the social, environmental, and economic domains, a sustainable development goals-centered approach, and a post-sustainability-centered approach, which emphasized sustainability, existence, and relationality. Additionally, time was allocated for group discussions and sharing sessions on the content of "Sustainable Happiness" by O'Brien (2010), providing an opportunity for participants to reflect on the relationship between personal subjective happiness and ecologically responsible behavior.

Moreover, participants were required to keep an ecological journal containing contents related to "personal happiness, community happiness, and global happiness (including three categories each)" for three days, which were then shared and discussed with group members. This activity can be related to the "self-organization" process, one of the elements of complexity theory.

In the second stage of the course, various issues related to sustainable development were shared and discussed, and strategies for integrating complexity theory into education for sustainable development were brainstormed in groups. In the third stage, through group discussions on how to structure the teaching demonstration assessment form, considerations were made on what should be emphasized when developing instructional materials for teaching demonstrations. Additionally, instructional demonstration materials applying the concepts of sustainable happiness and complexity theory focused on in this research were developed as drafts, and improvements were made through peer feedback. Finally, in the fourth stage of the course, teaching demonstrations were conducted by groups, and evaluations were conducted by instructors, peers, and self-evaluations. The groups then shared their evaluations to analyze and discuss improvements that need to be made in instructional materials and the process of teaching demonstrations. Furthermore, a pre-service teacher conference was held, centered on the content of all the processes so far, allowing participants to share their experiences and thoughts with experts and students who did not participate in the research. Subsequently, individual reflective journals were written to summarize thoughts and impressions after participating in this research.

3.2. Characteristics of instructional materials designed by pre-service science teachers

The 21 pre-service science teachers participating in this study were divided into four groups, and they developed integrated education for sustainable development instructional materials incorporating sustainable happiness and complexity theory into science education, scheduled for block time (two class periods of 100 minutes each). Firstly, Group 1 designed the lesson theme as "Our Earth in Crisis: Living Within Its Collapse," Group 2 as "The Pain of the Earth: No More," Group 3 as "Let's Become Detectives to Solve the Disappearance of Bees on Earth," and Group 4 as "Me and Our Climate Change." Each group established lesson objectives, and brief lesson plans, and summarized the characteristics of the core curriculum and integrated curriculum, as shown in **Table 1**.

Table 1. Characteristics of teaching and learning materials that integrate sustainable happiness and complexity theory designed by preservice science teachers

Class theme	Major learning objectives	Key teaching and learning flow	Core curriculum and integrated curriculum
[Group 1] Our Earth in Crisis: Living Within Its Collapse	(1) Can explain the impact of individuals' lives on environmental issues. (2) Can understand the relationship between environmental issues and sustainable happiness. (3) Can creatively design ways for social involvement related to environmental issues.	(1) Explore behaviors influencing environmental issues in personal life. (2) Understand the relationship between environmental issues and sustainable happiness. (3) Encourage planning and implementation of challenges for solving environmental problems.	(1) High School Level 1 Integrated Science (Biodiversity and Conservation, Renewable Energy and Sustainable Development) (a) High School Level 1 Integrated Social Studies (Understanding from an Integrated Perspective, Conditions for Achieving Happiness, Various Efforts for Solving Environmental Issues)
[Group 2] The Pain of the Earth: No More	(1) Understanding the Interconnection of Air, Water, Soil, and Marine Pollution (2) Creating a Personal Environmental Action List and Developing Action Plans (3) Reflecting on the Connection between Subjective Happiness and Ecologically Responsible Happiness	(1) Providing Opportunities to Reflect on the Interconnection between Environmental Issues and Personal Life (2) Using the Jigsaw Cooperative Learning Model to Discuss Environmental Problem Causes and Impacts (3) Creating Environmental Action Lists and Four-panel Cartoons	(1) High School "Environment" (Environmental Events and Cases: Water, Atmosphere, Soil, Biology, Climate Change, Energy) (a) High School 1 Integrated Science (Conservation Methods for Biodiversity, Ecosystem Balance, Climate Change) (b) High School 1 Integrated Social Studies (Natural Environment and Human Life) (c) High School "Earth Science" (Interaction between Atmospheric Pollution and Marine Pollution)
[Group 3] Let's Become Detectives to Solve the Disappearance of Bees on Earth	(1) Through emergent thinking processes, one can understand the causes of bee disappearance in a balanced manner. (2) One can design scientific solutions to the issue of bee disappearance. (3) One can recognize the relevance between the disappearance of bees and sustainable happiness.	(1) Explore the issue of bee disappearance through articles. (2) Devise solutions to address the problem of bee disappearance. (3) Explore the effectiveness of implementing solutions to the issue of bee disappearance.	(1) High School 1 Integrated Science (Ecosystem Balance) (a) High School 1 Integrated Social Studies (The Future Global Village and Our Lives) (b) High School 1 Technology and Home Economics (Sustainable Development) (c) High School 1 Life and Ethics (Responsibility for Future Generations) (d) High School 1 Art Creation (From Concept to Expression)
[Group 4] Me and Our Climate Change	(1) Understand and reflect on the impact of climate change on individual lives. (2) Explain how changes in the interaction between the atmosphere and the oceans affect the global environment and human life. (3) Predict changes in the global environment due to climate change and develop strategies to overcome them.	(1) Understanding and reflecting on the impact of individual actions on climate change. (2) Understanding the potential impact of changes in the global environment on individuals and society. (3) Exploring solutions to global warming from various economic, social, and cultural perspectives.	(1) High School Grade 1 Integrated Science (The Future of Earth, Global Warming and Climate Change, Ecosystems and Biodiversity, Ecosystem Conservation) (a) High School Grade 1 Integrated Social Studies (Balance and Happiness of Environment, Society, and Economy, Natural Disasters, Government and Civil Society Responses, Environmental Issues and Solutions)

3.3. Setting and analysis of classroom assessment criteria

The classroom assessment criteria utilized in this study, as shown in **Table 2**, are broadly categorized into three areas: ESD, sustainable happiness, and complexity theory.

Table 2. Criteria for class diagnosis incorporating ESD, sustainable happiness, and complexity theory

Criteria for classroom assessment	Items for classroom assessment	
Overall assessment of ESD	Were the instructional content and strategies effectively addressed in the teaching-learning process and classroom demonstrations to impart the "basic knowledge" set?	
	Were the instructional content and strategies effectively addressed in the teaching-learning process and classroom demonstrations to foster the "skills and competencies" set?	
	Were the instructional content and strategies effectively addressed in the teaching-learning process and classroom demonstrations to cultivate the "perspectives and viewpoints" set?	
	Were the instructional content and strategies effectively addressed in the teaching-learning process and classroom demonstrations to instill a "values" set?	
	Were the instructional content and strategies effectively addressed in the teaching-learning process and classroom demonstrations regarding the key aspects of the "environment, society, economy, and happiness dimensions" set?	
Assessment of integration with sustainable happiness	Were opportunities provided to consider "subjective happiness" and "ecologically responsible behavior"?	
	Were opportunities provided through self-reflection to contemplate the happiness of both individuals and members of society?	
	Were opportunities provided to understand the interaction between individuals and society and to establish desirable relationships for sustainable happiness?	
Assessment of integration with complexity theory	Self-organization integration	Were opportunities provided for learners to understand their relationships with their surroundings and with others?
		Were opportunities provided for learners to understand their existence and life while comprehending the dynamic context of society?
		Did self-reflection opportunities enable learners to confirm their values and transform them into values for sustainable living?
	Emergence integration	Were opportunities provided for learners to use divergent thinking to lead the interconnectedness of various perspectives existing in our society?
		Were opportunities provided for learners to discover new and consistent structures, properties, patterns, etc., among various elements?
		Did the learning process provide opportunities for students to have autonomy in finding their own learning objectives during the course?
	Fractal integration	Were opportunities provided for learners to draw fractal images containing self-similar repetitions, recursion, and feedback loops?
		Were opportunities provided for repeated trial and error, learner-driven self-directed learning?
		Were opportunities provided for learners to engage in open communication to understand the interactions and balance points among social, environmental, and economic domains?

Firstly, the classroom assessment criteria for ESD were established based on the learning objectives of learners included in the teacher education guidelines for sustainable development compiled from UNESCO and McKeown's research [27,41]. These criteria focus on learners' learning objectives (basic knowledge, skills, perspectives, values) and elements included in the sustainability compass (nature, happiness, society, economy).

Secondly, to establish the classroom assessment criteria for sustainable happiness, three key contents extracted from O'Brien's study [7], which first introduced the concept of sustainable happiness in sustainability education, were included in the assessment criteria. Therefore, the content was set to provide opportunities for contemplating "subjective happiness" and "ecologically responsible happiness," experiences of self-reflection, and exploration of the relationship between individuals and society.

Lastly, for the three important concepts of complexity theory - self-organization, emergence, and fractals - classroom assessment criteria for each concept were established based on the research by Davis and colleagues [13,14]. For self-organization-related assessment criteria, opportunities for understanding the relationship between learners and their surroundings, understanding one's existence and life in a social context, and confirming one's values and transforming them into values for sustainable living were included. For emergence-related assessment criteria, opportunities for exploring the interconnectedness of various perspectives existing in society, discovering new and consistent structures or properties among various elements, and finding their own learning objectives were included. Lastly, for fractal-related assessment criteria, opportunities for drawing images including self-similar repetition, cycles, and feedback loops, trial-and-error and self-directed learning opportunities, and understanding the interactions and balance points among the social, environmental, and economic domains were included.

The results of the normality test for the classroom assessment criteria items of ESD, sustainable happiness, and complexity theory integrated into **Table 2** are presented in **Table 3**. Based on these items, professor evaluation, peer evaluation, and self-evaluation were conducted using a 5-point scale. Statistical results were derived using IBM SPSS 28.0 to analyze quantitative data.

Table 3. The results of the normality test of the class diagnosis criteria question

Classroom diagnostic compliance		Shapiro-Wilk		
		Statistics	Degrees of freedom	CTT significance
ESD		0.919	16	0.164
Sustainable happiness		0.883	16	0.043
Complexity theory integration	Self-organization	0.877	16	0.035
	Emergence	0.884	16	0.045
	Fractals	0.929	16	0.233
	Overall	0.953	16	0.547

Minimum significance level. Lilliefors significance probability adjustment.

Additionally, in addition to the quantitative analysis above, qualitative analysis of classroom materials and demonstration processes was conducted contextually by repeatedly examining observation notes recorded by the researcher during participation observation of classroom demonstrations and reviewing demonstration video recordings. Furthermore, based on the peer evaluation results of prospective science teachers for the classroom demonstration, correlations between classroom demonstration assessment criteria for ESD (integration of basic knowledge, skills and competencies, perspectives and viewpoints, values, integration of environmental, social, economic, and happiness aspects), assessment criteria for sustainable happiness, and complexity theory (self-organization, emergence, fractals) were analyzed.

3.4. Analysis of changes and reflections of prospective science teachers before and after research participation

Firstly, changes in awareness regarding the meaning of ESD and the necessity of its integration into science education were analyzed using qualitative content analysis. To achieve this, the contents described in the pre-research opinion sheets and reflective journals written by prospective science teachers before and after research participation were compared.

Next, before and after research participation, the confidence of prospective science teachers in applying

ESD to science education was examined using a Likert 7-point scale self-report format. The normality test confirmed the absence of a normal distribution, thus the Wilcoxon signed-rank test was conducted to ascertain the mean difference before and after research participation.

Furthermore, differences in the teacher orientation of prospective science teachers before and after research participation were analyzed, focusing on the relevant content in reflective journals. Words that underwent refinement and preprocessing were transformed from a two-mode (word document) to a one-mode (word-word) network, analyzing the structure of word relationships in reflective journals of prospective science teachers overall. A co-occurrence range of 3 was set for concurrently appearing words. Subsequently, to identify keywords in the network of extracted words, those with a total frequency of 3 or more and a co-occurrence frequency of 2 or more were extracted for analysis. Clustering network analysis was conducted to identify clusters comprising words with many links in the overall text network. All analyses were conducted using NetMiner 4.4.3. During the process of explaining and finding meaning in the analyzed cluster structure using the program, the reflective opinions of prospective science teachers were qualitatively confirmed to ensure the accuracy of content interpretation.

Additionally, reflections on the research participation process included in the reflective journals written by prospective science teachers were analyzed. Through analysis of these reflections, prospective science teachers' thoughts and feelings during the research participation process were revealed, indirectly allowing for an assessment of the effectiveness of integrating the concepts of sustainable happiness and complexity theory applied in this research.

4. Research results and discussion

4.1. Analysis of teaching demonstrations based on instructional materials set (1) prepared by prospective science teachers

4.1.1. Analysis according to ESD teaching criteria

The results of peer evaluation based on ESD teaching criteria such as "basic knowledge, skills and competencies, perspectives and viewpoints, values, environment, society, economy, and happiness" are presented in **Table 4**. The average score for all assessment items was high at 4.58 points on a 5-point scale. However, it was analyzed that relatively lower scores were received in the "basic knowledge" and "environment, society, economy, and happiness" integration sections.

Table 4. Peer evaluation results according to ESD class diagnosis criteria

ESD criteria	Mean	Standard deviation	*n*
Incorporation of basic knowledge	4.48	0.43	16
Incorporation of functions and competencies	4.62	0.38	16
Incorporation of perspectives and views	4.62	0.39	16
Incorporation of values	4.62	0.41	16
Incorporation of environment, society, economy, and happiness	4.54	0.37	16
Overall	4.58	0.32	16

To better understand the characteristics of the teaching demonstrations, qualitative analysis results related to the aspects well highlighted by each group among the five ESD criteria, such as "perspectives and views integration" and "environment, society, economy, and happiness integration," are presented in **Table 5**.

Table 5. Qualitative analysis according to ESD class diagnosis criteria

ESD criteria	[Group 1] Our Earth in Crisis: Living Within Its Collapse	[Group 2] The Pain of the Earth: No More	[Group 3] Let's Become Detectives to Solve the Disappearance of Bees on Earth	[Group 4] Me and Our Climate Change
Integration of perspectives and views	(1) Recognition of the cyclical causal relationships among science, technology, and societal factors (2) Understanding of contrasting perspectives such as individual vs. societal, logic vs. emotion, nature vs. human	(1) Awareness of the relationship between environmental pollution and our lives (2) Understanding of the organic interconnectedness among various factors related to environmental issues	(1) Ability to view a phenomenon from various perspectives (2) Capability to approach problem-solving with a balanced perspective across diverse domains	(1) Recognition of how climate change can conflict with individual values from an economic standpoint (2) Understanding of how climate change can impact not only individuals but also societal happiness
Integration of environment, society, economy, and happiness	(1) Environment: Understanding of ecosystem conservation (2) Society: Encouragement of social awareness and participation in environmental pollution issues (3) Economy: Discussion of the economic aspects of plastic usage (4) Sustainable happiness: Understanding the relationship between the environment and personal happiness	(1) Environment: Understanding the interrelation of air, water, soil, and marine pollution (2) Society: Exploration of community-sharing approaches regarding environmental pollution issues (3) Economy: Exploration of the economic impact of environmental pollution (4) Sustainable happiness: Awareness of the relationship between our lives and environmental pollution	(1) Environment: Exploration of various species interacting with bees (2) Society: Exploration of scientific solutions to societal issues (3) Economy: Exploration of the economic impact of bee extinction (4) Sustainable happiness: Exploration of the relationship between bee extinction and sustainable happiness	(1) Environment: Understanding of climate change phenomena (2) Society: Exploration of societal solutions to climate change (3) Economy: Understanding of the economic aspects considered in climate change strategies from personal and societal perspectives (4) Sustainable happiness: Awareness of personal happiness in participating in efforts to address climate change

4.1.2. Analysis according to sustainable happiness teaching criteria

Analyzing the teaching demonstration process based on the three teaching criteria for sustainable happiness, the results are shown in **Table 6**. Overall, high scores were received for all three criteria.

Table 6. Peer evaluation results according to "sustainable happiness" class diagnosis criteria

Criteria for sustainable happiness	Mean	Standard deviation	*n*
Providing opportunities for considering subjective happiness and ecologically responsible behavior	4.64	0.39	16
Providing opportunities for considering the happiness of individuals and members of society through self-reflection	4.60	0.40	16
Providing opportunities for considering relationship establishment for sustainable happiness	4.62	0.52	16
Overall	4.62	0.36	16

Qualitative analysis of the teaching demonstration process according to the sustainable happiness teaching criteria revealed that Group 1 provided opportunities for students to directly contemplate the concept of sustainable happiness by utilizing an ecological journal at the introduction stage of the lesson. Group 2 offered opportunities for students to consider sustainable happiness based on systematic thinking while exploring environmental issues during the lesson. Group 3 made efforts to address and integrate "sustainable happiness" throughout the entire lesson, while Group 4 actively integrated it at the beginning of the lesson, but faced difficulties in continuous integration throughout the lesson process. They made efforts to address it again after the lesson, although the flow did not naturally connect. Specific details are provided in **Table 7**.

Table 7. Qualitative analysis according to "sustainable happiness" class diagnosis criteria

Criteria for sustainable happiness	[Group 1] Our Earth in Crisis: Living Within Its Collapse	[Group 2] The Pain of the Earth: No More	[Group 3] Let's Become Detectives to Solve the Disappearance of Bees on Earth	[Group 4] Me and Our Climate Change
Providing opportunities for considering subjective happiness and ecologically responsible behavior	Encouraging natural recognition of the impact of one's life on the environment through the process of writing one's ecological journal	Providing opportunities for reflecting on one's life and its connection to environmental issues through the analysis of public service advertisements on environmental problems	Exploring the impact of the disappearance of bees in the early stages of the class and revisiting it later to confirm changes in one's thoughts	Providing opportunities for thinking about subjective happiness and ecologically responsible behavior by sharing one's daily life in a vlog with peers
Providing opportunities for considering the happiness of individuals and societal members through self-reflection	Encouraging individuals to contemplate the conditions they perceive as happiness and discuss their relevance to others and the natural environment	Providing opportunities for reflecting on the happiness of individuals and society by compiling a list of environmental practices based on self-reflection	Offering opportunities for self-reflection by writing value statements about sustainable happiness and its reflection on one's own life	Providing opportunities for reflection on the impact of one's life on climate change while exploring practical measures for sustainable happiness
Providing opportunities for establishing relationships for sustainable happiness	Offering opportunities for redefining values through the creation and sharing of a checklist for confirming personal values	Providing opportunities for contemplating the concept of sustainable happiness while exploring multifaceted solutions to environmental issues	Offering opportunities for contemplating sustainable happiness through considering the effects of implementing solutions to the disappearance of bees	Providing opportunities for reflecting on the impact of climate change on individuals and society, and considering the relationship between environmental issues and individuals and society from the perspective of sustainable happiness

4.1.3. Analysis according to complex theory teaching criteria

The instructional materials designed and demonstrated by prospective science teachers incorporated ESD and sustainable happiness, in addition to applying elements of complexity theory. The instructional criteria related to complexity theory include areas of "self-organization, emergence, and fractal," each consisting of three analysis items.

Among the overall analysis areas, the "fractal" area showed a relatively lower average score, while the instructional criteria for "self-organization" and "emergence" received almost similar average scores, as analyzed (**Table 8**).

Table 8. Peer evaluation results according to "complexity theory" class diagnosis criteria

Complexity theory criteria		Mean	Standard deviation	*n*
Self-organization integration	Providing opportunities to consider relationships with oneself, the surrounding environment, and others	4.48	0.47	16
	Providing opportunities for considering one's life within social contexts	4.26	0.71	16
	Providing opportunities for confirming personal values and considering value changes for sustainable living	4.60	0.36	16
Subtotal		4.45	0.42	16
Emergence integration	Providing opportunities to induce emergent thinking by fostering interconnectedness among diverse perspectives	4.56	0.46	16
	Providing opportunities to identify new and consistent structures among various elements	4.51	0.47	16
	Providing opportunities for students to find their own learning goals	4.32	0.67	16
Subtotal		4.46	0.48	16
Fractal integration	Providing opportunities to draw fractal images incorporating self-similar repetition, cycles, and feedback loops	4.25	0.57	16
	Providing opportunities for learners to repeatedly engage in self-directed decision-making learning	3.84	1.05	16
	Providing opportunities to understand interactions and balance points among society, environment, and economy	4.60	0.37	16
Subtotal		4.23	0.59	16
Overall		4.38	0.44	16

In the "self-organization" area, the item "providing opportunities for considering one's life in the social context and sharing it with others through the process of writing an ecological journal" received a relatively lower average score. In the "emergence" area, the item "providing opportunities for students to find their own learning goals" and in the "fractal" area, the item "providing opportunities for learners to repetitively perform self-directed learning" received relatively lower average scores compared to other criteria.

Analyzing the characteristics of teaching demonstrations applying instructional criteria for the three areas of complexity theory by each group, the following are observed:

For the teaching demonstration of Group 1 ("Our Earth in Crisis: Living Within Its Collapse"), self-organization was integrated by providing opportunities for contemplating one's life through the process of writing an ecological journal and sharing it with peers. Emergence was incorporated by providing opportunities for experiencing the emergence process through activities exploring environmental issues from various perspectives. Fractal was integrated by providing opportunities for understanding the interaction and balance among society, environment, and economy through activities drawing feedback loops related to emergence activities based on systemic thinking.

In the case of Group 2 ("The Pain of the Earth: No More"), self-organization experience was provided through opportunities to contemplate the connection between environmental issues and personal life. Emergence opportunities were provided by creating a mind map based on investigations into soil, air, ocean, and water pollution. The fractal experience was provided by understanding the relationships between various environmental pollution factors through the process of comprehending the interrelatedness.

In the teaching demonstration of Group 3 ("Let's Become Detectives to Solve the Disappearance of Bees on Earth"), opportunities for self-organization were provided by contemplating the impact of the disappearance of bees and the relationship with sustainable happiness. Emergence opportunities were provided through the process of finding solutions from various perspectives. Fractal experience was provided through activities exploring the causes and consequences of the disappearance of bees from various perspectives.

Lastly, in the teaching demonstration of Group 4 (“Me and Our Climate Change”), self-organization was integrated by providing opportunities for contemplating subjective happiness and ecologically responsible behavior. Emergence opportunities were provided through processes such as exploring various causes of climate change and understanding the relationship between individual actions and sustainable living. Although there was limited integration observed in the fractal aspect.

4.1.4. The correlation between ESD, sustainable happiness, and complexity theory integration

The results of the analysis of the correlation between ESD, sustainable happiness, and complexity theory integration are presented in **Table 9** below.

Table 9. The correlation between ESD factors, sustainable happiness, and complexity theory factors

		Integration of basic knowledge	Integration of functionality and capacity	Integration of perspectives and views	Integration of values	Integration of environment, society, economy, and happiness	Overall ESD
Sustainable happiness integration		0.598*	0.419	0.721**	0.849**	0.264	0.710**
Complexity theory integration	Self-organization	0.730**	0.507*	0.583*	0.624**	0.554*	0.742**
	Emergence	0.365	0.521*	0.643**	0.578*	0.579*	0.657**
	Fractal	0.541*	0.397	0.569*	0.670**	0.468	0.655**
Overall		0.607*	0.528*	0.673**	0.708**	0.596*	0.768**

**The correlation is significant at the 0.01 level (two-tailed). *The correlation is significant at 0.05 level (two-tailed).

Prospective science teachers believe that the more elements of sustainable happiness they provide, the more effectively they can handle fundamental knowledge, perspectives, and values. In other words, sustainable happiness elements can be analyzed as helping to effectively integrate fundamental knowledge, perspectives, and value aspects, which are the main elements of executing ESD.

Furthermore, the subfactor of self-organization in complexity theory shows a significant positive correlation with all elements of ESD. However, emergence shows no significant correlation with fundamental knowledge, and fractal shows no significant correlation with functionality and capacity. Moreover, the self-organization subfactor of complexity theory as a whole shows a significant positive correlation with each element of ESD. This indicates that integrating self-organization can effectively incorporate all elements of ESD into teaching. Additionally, it was analyzed that applying the entire complexity theory elements is more effective in integrating all elements of ESD compared to applying individual complexity theory elements.

Overall, when integrating sustainable happiness into ESD, effective teaching and learning strategies need to be developed to effectively reveal the elements of functionality and capacity, environment, society, economy, and happiness. Moreover, when there is a need to emphasize or complement the elements of fundamental knowledge, perspectives, and values in ESD, integrating sustainable happiness elements may be helpful.

Furthermore, since the elements of complexity theory show a positive correlation with overall ESD, complexity theory can be proposed as a core teaching strategy for ESD. Especially, considering that the subfactor of self-organization in complexity theory has a positive correlation with all elements of ESD, it is considered more effective to apply it more actively in situations where it is difficult to integrate all elements of complexity theory into lesson planning.

4.2. Pre-post perception change analysis of prospective science teachers

4.2.1. Changes in perception regarding the meaning of education for sustainable development and the need for integration into science education

The analysis of how the perception of prospective science teachers regarding the meaning of education for sustainable development and the necessity of integrating it into science education changed after participating in the research is shown in **Table 10**.

Table 10. Changes in pre-service science teachers‘ perception of the meaning of ESD and the need to integrate ESD into science education

The meanings of sustainable development education	Changes in perception before and after participation		The need for integration of science education and sustainable development education	Changes in perception before and after participation	
	Before	After		Before	After
Education on processes and methods for sustainable and eco-friendly development	9 (42.9%)	3 (14.3%)	Integration of sustainable development education and science education from a problem-solving perspective can be effective	8 (38.1%)	4 (19.0%)
Education on learning and practicing behaviors for individuals and society to live in future societies	6 (28.6%)	7 (33.3%)	Effective in addressing the role of scientific and technological development in human advancement and survival	7 (33.3%)	1 (4.8%)
Education aimed at creating new values while harmonizing the environment, society, and economy	2 (9.5%)	5 (23.8%)	Necessary for understanding the impact of scientific and technological advancements on society	4 (19.0%)	1 (4.8%)
Education on preserving the environment and conserving ecosystems	2 (9.5%)	3 (14.3%)	Sustainable development education commonly includes content related to the global environment such as environment, energy, and ecosystems	2 (9.5%)	4 (19.0%)
Education for responding to and contributing to social change	2 (9.5%)	0 (0.0%)	Integration with science is effective for understanding the diverse and convergent elements of sustainable development education	0 (0.0%)	4 (19.0%)
Education that induces practical actions for both individual and global happiness	0 (0.0%)	3 (14.3%)	The concept of sustainable happiness, necessary for understanding sustainable ways of life, should also be addressed in science	0 (0.0%)	7 (33.3%)
Total	21 (100%)	21 (100%)	Total	21 (100%)	21 (100%)

Initially, before participating in the research, prospective science teachers perceived education for sustainable development mainly as "education on sustainable and eco-friendly development processes and methods (42.9%)" and "education to learn and practice behavioral patterns for individuals and society to live in the future society (28.6%)." However, after participation, there was a relatively higher proportion of those who perceived it as "education to learn and practice behavioral patterns for individuals and society to live in the future society (33.3%)" and "education to create new values while achieving harmony in the environment, society, and economy (23.8%)."

Regarding the necessity of integrating science education and education for sustainable development, before participating in the research, some prospective science teachers believed it would be effective to integrate them because "the problem-solving perspectives of education for sustainable development and science education are related to each other (38.1%)" or "the role of scientific and technological development in human development and survival aspects can be addressed (33.3%).” However, after participation, there was a relatively higher percentage of those who expressed the opinion that “the concept of sustainable happiness for understanding sustainable ways of life needs to be addressed in science as well (33.3%).” Additionally, opinions indicating the necessity of integration were more diverse after participation, with perspectives such as “integration is needed due to the problem-solving aspects (19.0%), the inclusion of content on the global environment (19.0%), and dealing with various convergent elements (19.0%)” showing a dispersed understanding of the need for integration compared to before participation.

4.2.2. Changes in confidence regarding the integration of education for sustainable development in middle school science education

The results of the perception change of prospective science teachers regarding their confidence in integrating education for sustainable development into their science classes before and after participating in the research, as measured on a 7-point scale, are shown in **Table 11**. The average score increased significantly by 1.8 points from before participation (average 3.4 points) to after participation (average 5.2 points), indicating a highly significant statistical result ($P < 0.001$). These results suggest that applying the core elements of sustainable development education, focusing on sustainable happiness and complexity theory, has greatly helped restore the confidence of prospective teachers in integrating education for sustainable development into their teaching practices.

Table 11. Changes in the perception of pre-service science teachers' confidence in integrating ESD in science classes

Separation	*n*	Pre-score		Post-score		Standardized test statistics	*P*
		Mean	Std. dev.	Mean	Std. dev.		
Integrated sustainable development education lesson	19	3.4	1.50	5.2	0.96	3.457	0.000***

***$P < 0.001$

4.2.3. Changes in prospective science teachers' teaching orientations after research participation

The differences in teaching orientations between prospective science teachers before and after research participation were examined through cluster network analysis, as shown in **Figure 1**.

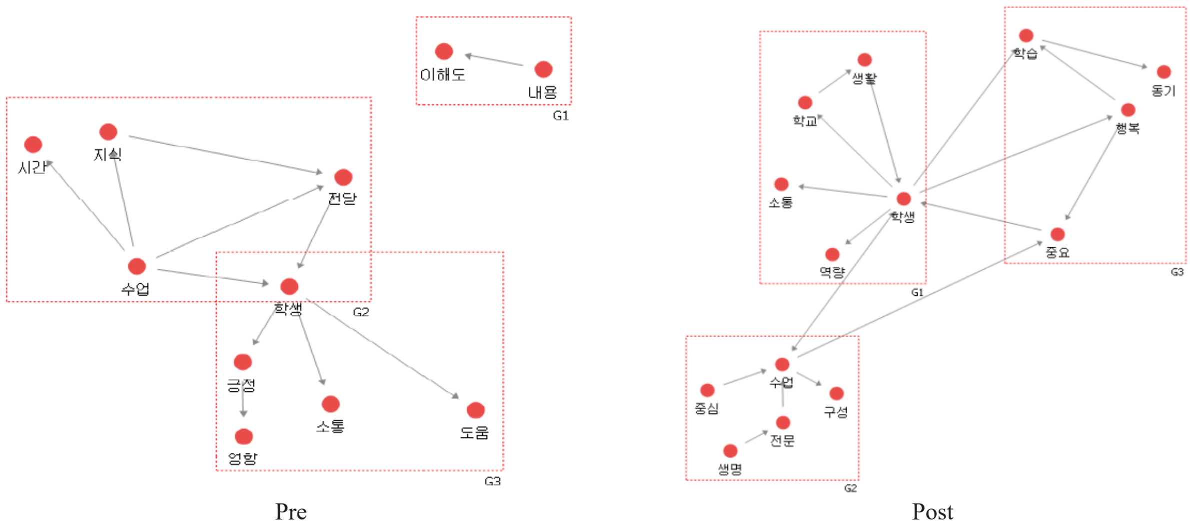

Figure 1. Pre-post cluster network analysis of teacher orientation of preservice science teachers (deselect isolated nodes)

In the pre-participation language network cluster structure of prospective science teachers' teaching orientations, Group 1 (G1) included words such as "understanding" and "content," indicating a focus on facilitating understanding of the content. Group 2 (G2) contained words like "class," "knowledge," "delivery," and "time," suggesting an orientation towards effectively delivering knowledge during class time. Group 3 (G3) featured words such as "student," "communication," "influence," "help," and "positive," indicating a teaching orientation focused on communicating with students, positively influencing them, and providing assistance.

Overall, science teachers perceived delivering knowledge to students during class time as important, while also showing interest in communicating with students and positively influencing them.

After participating in the research, the analysis of post-research teaching orientations revealed that in Group 1 (G1), words such as "student," "school," "life," "communication," and "competence" appeared, indicating a focus on fostering communication and competence-building among students both at school and in daily life. In Group 2 (G2), words like "class," "organization," "focus," "professional," and "life" emerged, suggesting consideration of organizing class content related to life professionally. In Group 3 (G3), words such as "learning," "motivation," "happiness," and "importance" appeared, indicating a focus on motivating students to learn and address happiness during class time.

Overall, prospective science teachers were found to have teaching orientations centered around not only structuring and delivering content professionally but also enhancing students' learning motivation, fostering communication with students, developing their competencies, and addressing elements necessary for students to lead happy lives.

4.3. Analysis of prospective science teachers' reflections on research participation

Prospective science teachers' reflections written after participating in the research were qualitatively analyzed, and categorized into three main aspects as follows:

4.3.1. Opportunities for cultivating expertise in integrated and convergent sustainable development education

Through research participation, prospective science teachers had the opportunity to explore integrated science education strategies they had previously encountered only theoretically. They were able to develop teaching materials for expanded convergent science education by utilizing the concepts of sustainable happiness and fractal-emergent structures. This process was analyzed as fostering expertise in the integration of science education and sustainable development education. Below are examples of prospective science teachers' reflections related to this aspect:

"It was the first time I structured a lesson and conducted a class demonstration by integrating complexity theory and sustainable happiness into science education. This activity provided me with a chance to deeply contemplate how to integrate not only the four fields of science but also various disciplines to create a holistic approach. Through this, I gained an understanding of teaching methods that raise students' awareness of the socially significant concepts of sustainable development and sustainable happiness." (Reflection from PST 4)

"The activity of using fractal-emergent structures to connect commonalities between macroscopic topics such as environment and science and forming cyclic structures was very intriguing. As a prospective science teacher, this was a meaningful activity as it allowed me to gain skills not only in teaching techniques but also in environmental ethics." (Reflection from PST 10)

"I developed the lesson plan under the detective concept named 'Bee Colony Collapse,' focusing only on scientific knowledge-related content. However, when I associated it with sustainable development education, I realized that I could try more diverse approaches in class. It was an enlightening experience." (Reflection

from PST 3)

"I developed teaching materials and conducted class demonstrations connecting climate change problem-solving strategies with sustainable happiness, contemplating how to teach happiness not only to the current generation but also to the next generation. It was a meaningful time." (Reflection from PST 14)

4.3.2. Exploration of teaching strategies for sustainable development education based on new perspectives and approaches

The perspective or approach to integrating sustainable development education into curriculum education can vary depending on the educational goals set by the instructor. In this research, the process of designing and demonstrating science classes applying three key elements of sustainable happiness concept and complexity theory, which have rarely been addressed in school classes, was undertaken. It was analyzed that through this process, prospective science teachers not only gained an understanding of new perspectives and approaches they had not experienced before but also had the opportunity to encounter various teaching strategies for sustainable development education. Examples of prospective science teachers' reflections related to this aspect are as follows:

"The term 'sustainable development' was something I had heard even during my secondary school years, so initially, I thought it would be repetitive content. However, the sustainable development education I experienced this time covered a much broader scope, giving me plenty of new things to think about. It was impressive to structure the class by applying elements that were not covered in previous typical classes." (Reflection from PST 6)

"The class demonstration this time was quite diverse and required meeting many conditions. I designed a class that addressed social issues according to the curriculum of the grade, incorporating sustainable happiness, self-organization, emergence, and fractal structures. Through this experience, I believe I have gained not only the ability to incorporate complexity theory and the concept of sustainable happiness into classes but also the ability to apply various approaches to teaching." (Reflection from PST 18)

"When developing teaching materials, I repeatedly pondered on how to make it easy for learners encountering unfamiliar learning perspectives such as feedback loops and emergence for the first time to understand. Overcoming the initial difficulties and trying new approaches in developing sustainable development education materials made me proud." (Reflection from PST 20)

"It was an opportunity to consider how to structure classes from the perspective of students, so that they could learn about self-organization, emergence, systems thinking, and fractal elements, and to conduct classes according to the teacher's educational intent." (Reflection from PST 21)

4.3.3. Creating opportunities for change and growth as prospective science teachers through collaboration

Prospective science teachers had the opportunity to reflect on their lives and experience numerous trial-and-error processes while exploring teaching and learning strategies that integrate science education and sustainable development education through collaboration in this research. They also realized the importance of sustainable development education and its integration into science education, and through sharing ideas on teaching strategies and constructing teaching materials with colleagues, they experienced personal transformation and growth. Examples of prospective science teachers' reflections related to this aspect are as follows:

"I learned a lot and felt a lot during the process of developing teaching materials, preparing for class demonstrations, and executing them together with team members. I learned how to design and organize classes, realized the importance and effectiveness of the collaborative process of developing a single class, and through

this process, I came to understand the importance and value of sustainable development education. Although it was sometimes overwhelming, I think it was a very meaningful experience because I was able to learn and grow a lot from it." (Reflection from PST 15)

"I felt like I could gain a deeper understanding of sustainable development through this opportunity because I was able to experience teaching theoretical content through class demonstrations. Although I have not been practicing sustainable development in my daily life, through class demonstrations, I was able to learn about the importance of sustainable happiness from various perspectives, and I hope to continue striving for sustainable development education in the future." (Reflection from PST 5)

"Through one semester of developing a single project and carrying out activities, I was able to gain many experiences. It was a significant time during which I learned how to conceive and materialize my classes through numerous trial-and-error processes. It was a class where I realized the importance of cooperating with all team members during the team project process." (Reflection from PST 16)

"We had a good time with team members developing lesson plans, creating materials, and going through the overall process for class demonstrations based on the theme of bee disappearance. It was a valuable time to explore how elements of sustainable development education could be applied to classes." (Reflection from PST 17)

"I focused on designing classes to help students understand climate change within the context of various complex relationships in sustainable living. Developing sustainable development education teaching materials was not easy, but it was a meaningful time when I could share many thoughts and opinions with team members during the class design process." (Reflection from PST 8)

"Through activities designing classes for sustainable happiness, I learned how to incorporate feedback loops and emergence into classes. It was also an opportunity for me to think and reflect on what sustainable happiness is." (Reflection from PST 13)

5. Conclusion and recommendations

In this study, prospective science teachers were encouraged to integrate the key elements of sustainable happiness and complexity theory into their teaching materials and class demonstrations. The changes in their attitudes and practices before and after participating in these educational activities were analyzed from various perspectives. The aim was to derive implications for enhancing the multidimensional professional competence of prospective science teachers in integrating sustainable development education into science education.

According to the peer evaluation results of the teaching materials and class demonstrations designed by prospective science teachers, the average scores for integrating sustainable happiness were relatively higher than those for integrating sustainable development education as a whole and complexity theory. Particularly, lower scores were observed regarding aspects such as connecting students to social contexts and their own lives, guiding students to find the objectives of the class by themselves, and providing opportunities for learner-driven decision-making. If prospective science teachers have sufficient opportunities to explore teaching and learning strategies for integrating community-based science education and sustainable development education, it is believed that this can help them develop expertise in this area.

The elements of sustainable happiness and complexity theory were found to have a generally positive correlation with sustainable development education. Therefore, there is a need to develop teaching and learning models centered around complexity theory to understand the relationship between students' subjective happiness and ecologically responsible behavior within the context of science education. These models should be tailored to the characteristics of the education target, such as the new national science curriculum, local curriculum, and characteristics of the students and classroom environment.

Prospective science teachers showed an increased understanding of sustainable development education as a strategy for integrated science education, expanding the content and methods of sustainable development education. Through designing and demonstrating classes applying the concepts of sustainable happiness and complexity theory, they gained experiences that would help them develop innovative skills in future teaching practices. This process enabled prospective science teachers to recognize the importance and value of sustainable development education in science education and to reflect on their own lives, thus evolving into teachers who can bring about self-transformation and growth through teaching.

In conclusion, prospective science teachers need to continue exploring strategies for applying sustainable happiness and complexity theory in science education. After participating in this research, they not only developed professional content knowledge for teaching but also adopted a teacher-oriented approach focused on enhancing students' learning motivation, communication skills, and understanding of the elements necessary for a happy life. The comprehensive research process conducted in this study could serve as a model for cultivating the interdisciplinary professional competence of prospective science teachers in the future.

Disclosure statement

The author declares no conflict of interest.

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