

RESEARCH ARTICLE

Identification of Brain Activity Patterns of Junior High School Students' Learning on Metaverse-based Ecosystem: An fNIRS Study

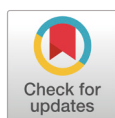
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ABSTRACT

This study aims to identify the brain activation patterns of middle school students during their learning activities based on the metaverse-based ecosystem. The metaverse-based ecosystem of 13 species inhabiting coastal reefs was designed for the learning program of the experimental group, while the control group was provided with a Zoom learning program with the same content. Analyzing the average brain activity within the metaverse-based ecosystem revealed predominantly left-sided brain activation in the fNIRS system. This suggests heightened activity in areas associated with visual stimuli and observational learning tasks characteristic of the metaverse. General Linear Model (GLM) analysis indicated increased activity in the left Ventrolateral Prefrontal Cortex (VLPFC) region and decreased activity in the left Dorsolateral Prefrontal Cortex (DLPFC) region, indicating engagement in interactions with objects and others during inquiry activities within the metaverse-based ecosystem. Comparative analysis with a control task showed reduced activity in the right Orbitofrontal Cortex (OFC) region related to negative emotions and in the Frontopolar (FP) region associated with goal-oriented thinking and metacognition. This suggests a shift in affective and cognitive domains compared to non-face-to-face platforms, with students exhibiting relatively positive emotions but reduced goal-oriented thinking when using the metaverse.

Key words: Metaverse-based ecosystem, learning biology, fNIRS, brain activation, junior high school



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Introduction

An ecosystem is a large structure of life systems that starts from a cell and includes various components such as individual individuals, populations and communities, and elements of the abiotic system, as well as complex dimensions of life phenomena (Westra, 2008). Considering the characteristics of ecosystems, ecosystem education as a branch of biological education includes

learning activities in which students understand and generate systematic knowledge about ecosystems by exploring the interaction and role of each component in an ecosystem (Lee & Kwon, 2019; Westra, 2008). In particular, due to its academic nature, ecosystem education is not limited to traditional explanatory teaching methods in the classroom, but it is necessary to consider emotional experience as well as the ability to inquire through direct experience of ecology (Ojo & Kwon, 2023). Zhang et. Al. (2022) explained that this traditional form of descriptive learning makes it difficult to connect with the subject's direct experience and activate emotional learning mechanisms. Therefore, it has been suggested that ecological learning activities enhance both learning and emotional effects when they are conducted indoors and outdoors in parallel with exploration activities, including direct observation of biological phenomena (Cheon & Kim, 2018; Kim & Song, 2020; Korfiatis & Tunnicliffe, 2012; Tilling, 2002).

However, although the educational effects of outdoor learning activities, including direct observation and exploration, are recognized in ecological education in schools, outdoor learning activities are limited due to a lack of relevant information, difficulty in visiting activity sites, time and space constraints, and safety issues (Behrendt & Franklin, 2014; Kim & Lee, 2008; Park et al., 2007). In order to overcome these limitations, activities can be carried out through the Metaverse. Metaverse is a compound word of 'meta', which means virtual and transcendence, and 'universe', which means world and universe, and it refers to another world where the virtual and the real interact and social, economic, and cultural activities are carried out in it, creating value (Zhang et al., 2022). The Metaverse can be used as an alternative solution to the problem of high-cost, high-risk education (Kuznetcova et al., 2019; Lee, 2023), and since they can indirectly experience real space and place, it is possible to carry out educational activities that transcend time and space. In addition, since teenagers are already familiar with it, it is expected that if the Metaverse is used, it will be relatively easy to overcome the limitations in outdoor ecosystem exploration activities.

Various approaches and application results are also presented to utilize the characteristics of the Metaverse in education. Byeon (2022) presented an example of how a biological inquiry program using the Metaverse platform can positively affect the defining domain of elementary science-gifted children and provide opportunities for student interaction. Furthermore, highly operable digital learning environments provided by the Metaverse and Digital Twin have the potential to enrich educational content, enabling more specific and direct ecological education lessons and stimulating learners' ecological emotions (Baryła-Matejczuk et al., 2022; Byeon & Kwon, 2022; Ogbanje & Kwon, 2023).

As such, various studies are being conducted on the educational effects of the Metaverse, but these studies are limited to the analysis of questionnaires and interviews on the effects of using the Metaverse. However, since all mental changes ultimately imply changes in the structure and function of the brain, the ultimate analysis of learning effects needs to be accompanied by a neurological analysis of the changes in the brain (Ansari & Coch, 2006; Kwon et al., 2009; McIntosh, 2005). In fact, all the mental and physical stimulation, as well as the stimulation of digital content such as the Metaverse, significantly affect the changes in the structure and function of the brain. Therefore, it is predicted that the impact of digital virtual content such as the Metaverse will be different from that of adults in the changes in the brain structure and function of the adolescent generation, who are called digital natives because they are exposed to the digital environment from birth (Kwon et al., 2014; Herther, 2009; Prensky, 2001). Therefore, to appropriately utilize digital content such as Metaverse in future education, it is necessary to analyze the brain activity of adolescent learners who use this content to

identify the characteristics of their activity patterns.

Therefore, this study analyzes junior high school students' brain activity characteristics when using the metaverse-based ecosystem by comparing them with online education methods such as Zoom to explain the effects of metaverse learning content on junior high school students' brains in a neurological way. The metaverse-based ecosystem is based on the coastal dune ecosystem, which transitions from the coast to the inland ecosystem. It includes 13 species of organisms and has been implemented in the metaverse for exploration. Changes in brain activity in adolescents were measured using functional near-infrared spectroscopy (fNIRS), and changes in brain activity were measured when learners conducted coastal dune ecosystem exploration activities in the metaverse-based ecosystem or Zoom-based online settings.

Research Methods

Participants

This study collected two classes of first-year middle school students in Chungcheong into experimental and control groups, respectively. The experimental group (age 12.58, SD) did learning activities using the metaverse platform for coastal dune ecosystems. In contrast, the control group carried out learning activities on the same content using the Zoom platform. Students participating in the study were informed that it was a study to measure brain activity in the frontal lobe by wearing a functional near-infrared spectroscopy (fNIRS) device, and it was conducted after obtaining the consent of the students and their parents. Among the students who participated in the study, right-handed students were selected as the final participants through the hand dominance test (Oldfield, 1971). The data of 20 students were finally analyzed, excluding those whose number of recognized channels was below the threshold. In addition, in order to minimize individual differences and ensure homogeneity among participants, we provided an opportunity to familiarize themselves with the Metaverse in advance. This study was conducted after receiving prior approval (KNUE-202212-SB-0447-01) from the Institutional Review Board (IRB) of the Korea National University of Education, as it is a study to measure brain activity in the frontal lobe. The sampling status of each group of research participants is shown in Table 1.

Table 1. Demographic information of the participant group

Learning Types	Number of participants	Gender	Age
Metaverse	12	M = 5	M = 12.58
		F = 7	SD = 0.49
Zoom	8	M = 2	M = 12.75
		F = 6	SD = 0.43

Procedure

Metaverse and Zoom Platforms

In this study, the Metaverse platform adopted for the experimental group's coastal ecosystem learning activities is the

ZEP (ZEP Co Ltd; <https://zep.us/>) platform. ZEP is a metaverse platform that allows up to 50,000 people to participate simultaneously. It focuses on two-dimensional pixel art and enables users to create specific domains for their pages. In addition, ZEP provides one-click access to the metaverse space with video, audio, and text messages, as well as a web browser, facilitating the construction and operation of the metaverse space (Kim et al., 2022). Furthermore, the ZEP platform has a relatively high degree of flexibility for users to manipulate the learning content in new ways (KERIS, 2023). Therefore, this study adopted the ZEP platform, which makes it easy to create and utilize tasks as a tool for Metaverse production.

In addition, the digital platform applied to the learning activities of the control group to be compared with the experimental group is the Zoom (<https://zoom.us/>) platform. The Zoom platform enables real-time online learning and interaction between learning participants. In particular, this platform is similar to a digital space that can be interacted with, like the virtual space of the metaverse. However, there are differences because it participates in learning with a real appearance rather than an avatar, so it was selected as a learning activity platform for the control group.

Learning Ecosystem with Metaverse and Zoom Platforms

The ecosystem model created by the learning project of the metaverse and Zoom platforms is the coastal dune ecosystem of Taean Fig. 1. The coastal dune ecosystem in Taean has unique environmental and biological conditions as a transition from the ocean to the inland ecosystem (Park, 2017; Yoon, Park, & Yoo, 2010). Therefore, the coastal dune ecosystem with high biodiversity was considered suitable for developing an exploratory activity project to observe various living organisms, and it was adopted as an ecosystem model for this study. In the metaverse-based ecosystem, digital teaching and learning materials were provided to explore 13 species of biological resources inhabiting the coastal dunes of Taean, including indicator species such as leopard lizard (*Eremias argus*), sandfish (*Argusia sibirica*), beach morning glory (*Calystegia soldanella*), whole barley pasture (*Carex kobomugi*), sweetbrier (*Rosa rugosa*), yellow-billed egret (*Egretta eulophotes*), sanderling (*Calidris alba*), far eastern curlew (*Numenius madagascariensis*), white plover (*Charadrius alexandrinus*), and anchored trail-catcher (*Cicindela anchors punctatissima*), Korean tiger beetle (*Candela transbaicalica* Motschulsky), oriental-longheaded grasshopper (*Acrida cinerea*), and sand-bubble crab (*Scopimera globosa*).



Fig. 1. The typical coastal sandy dunes in Korea

To develop a metaverse-based ecosystem with the typical coastal dunes in Taean, the typical topography of the coastal dunes, such as Fig. 2, was referenced, and the metaverse background was created based on this Fig. 2. Afterward, 13 species of creatures living in the coastal dunes were made and placed as objects, and when students approached the objects, they were able to observe the creatures by referring to videos such as the habitat environment and movement of the creatures.



a. ecosystem exploring in the developed metaverse map

b. Digital materials are provided in the developed metaverse-based ecosystem

Fig. 2. The developed metaverse-based ecosystem based on a typical coastal sandy dune using the ZEP platform

In this study, the content validity of the metaverse-based ecosystem was developed to identify the characteristics of brain activity in using the metaverse-based ecosystem, which was verified. In order to utilize the developed Metaverse ecosystem as an exploration activity task, a content validity test was conducted for a group of 7 experts to determine the validity of the suitability of the Metaverse, the suitability of the ecosystem exploration program, and the suitability of the implementation of biological species. Experts were selected from master's or doctoral degree holders who have experience in biology education research, such as ecosystems using Metaverse. As for the feasibility, the validity was verified by calculating the CVI (Content Validity Index). The results of the metaverse-based ecosystem program validation were confirmed to be valid, as the CVI value was 0.91.

In addition, for the production of the learning tasks of the metaverse-based ecosystem control group, the Zoom platform was selected to provide the same teaching and learning materials and environment, such as biological resources, excluding the spatial environment elements of the Metaverse. On the Zoom platform, the same teaching and learning materials and assignments provided by the metaverse-based ecosystem were provided in PowerPoint to guide students' learning activities.

Data Collection and Analysis

Paradigm Design and Data Collection

This study produced a block design fNIRS measurement task to measure brain activity in metaverse-based ecosystem

learning activities (Huettel et al., 2009). Since the block design method presents a series of active tasks, it can increase the reliability of the measurement result data by increasing the hemodynamic response manifested by the cognitive activity targeted by the researcher (Luke et al., 2021). The task presentation paradigm was carried out in the order of measurement guidance, rest and fixation, task guidance, and task performance. In the measurement guidance stage, the students' movements during the measurement were guided. In the rest and fixation stage, the students rested for 60 seconds with their eyes closed and then took a break for 60 seconds with their eyes open and looking at the blank screen. Later, the students were guided on their assignments in the assignment guidance stage. After that, for about 5 minutes, the coastal dune ecosystem exploration task was carried out on the Metaverse or Zoom platform. In the assignment, three students worked as a group, and the students freely explored the coastal dunes and the creatures that inhabit them and shared their thoughts on how the creatures adapted to their environment.

The f-NIRS measurement device used in this study was NIRSIT (Model: NS1-H20A, OBELAB Inc., Seoul, Korea), a head-mounted type near-infrared multichannel device used to measure the brain activity of learners Fig. 3. NIRSIT is a flexible hair band type used to fix the device on the forehead of the research participant. Based on the information from the transmitter and receiver sensors in the equipment, the prefrontal cortex region was divided into 48 regions, and the activity of the brain was analyzed by calculating the changes in the concentrations of oxidized hemoglobin (HbO_2) and deoxidized hemoglobin (HbR^2) (Park & Kwon, 2021).



Fig. 3. The NIRSIT instrument used in this study (OBELAB Inc., 2022)

During the entire measurement process, the measuring personnel were positioned outside the field of view to not interfere with the study participants' task performance, and the entire process was monitored. Two measuring personnel guided the study participants through the task and monitored the task performance during the measurement process Fig. 4. Measuring personnel one was located to the participant's right, providing measurement guidance and monitoring the participant's reaction on the metaverse screen. On the other hand, Measurer 2 stood behind the participant, accurately collecting brain activity data and setting the necessary markers. In order to prevent interference from external light sources, the optical characteristics of the equipment have blocked the intense light from the surroundings. After completing the task and measuring brain activity, the equipment was removed, and sufficient rest was provided.

Afterward, data on the difficulty, interest, and difficulty experienced by the research participants when performing the task were collected through questionnaires and interviews.



Fig. 4. fNIRS measurement during subject's task-taking

Data Analysis

In the ecosystem exploration based on the metaverse-based ecosystem environment and the Zoom environment, the brain activity data collected from the NIRSIT device was analyzed to investigate the brain activity areas of middle school students. fNIRS raw data were pre-processed for analysis, group block mean and general linear model (GLM) analysis. In pre-processing the original fNIRS data, we first assigned job numbers to different sections of each job based on the markers set during the measurement process. In addition, the high-pass filter (DCT 0.005Hz) and the low-pass filter (DCT 0.1Hz) were set respectively to eliminate noises such as breathing and heartbeat generated by the human body to minimize noise unrelated to brain activity signals, and the threshold value (SNR threshold) of the signal-to-noise ratio of all 48 channels was applied at 20dB, and channels that were less than that were below were excluded from the analysis. Based on stable brain activity with eyes closed, the signal was processed at designated intervals of 30 seconds out of 60 seconds. Individual data graphs were examined to identify and exclude channels with abnormal signals. Finally, the modified beer-Lambert's law (MBLL) (Delpy et al., 1988) was used to calculate the oxyhemoglobin concentration in millimoles.

After pre-treatment, the data was analyzed using Group Block Averaging (GBA) analysis and General Linear Model (GLM) analysis. In the GBA analysis, the average brain activity of each group using the Metaverse platform and the Zoom platform was identified. Afterward, GLM was used to set up an ideal signal model based on the data values of each channel and analyze the relationship with the actual signal. This was used to derive the regression coefficient β value of GLM, which accurately models the BOLD signal, and to estimate brain activity (Park & Kwon, 2021). Then, when the brain activity of the ecosystem metaverse was compared with the brain activity of the control exploration activity by subtraction, the difference was confirmed, and statistically significant results were obtained. All GLM analysis results were t-tested, and only channels showing significant brain activity at the level of $\alpha = 0.05$ were extracted.

The anatomical location and activity of the statistically significant active channels were visualized, and each channel's anatomical regions and Brodmann regions were identified.

Results and Discussions

Brain Activation on Learning with Metaverse

The results of GLM analysis of brain activity in conducting exploration activities using the metaverse-based ecosystem are shown in Table 2, and it is Fig. 5 when displayed as brain activity images. When looking at the brain activity area, we saw a statistically significant increase in brain activity in channel 44, which corresponds to the left VLPFC region. On the other hand, channels 20 and 38, which correspond to the left DLPFC region, showed a statistically significant decrease in brain activity. Block averaging results showed that areas of increased or decreased brain activity tended to be ubiquitous on the left side.

Table 2. GLM analysis based on brain activity data using ecosystem metaverse

Region	THREE	Hemisphere	Channel	t
VLPFC	46	L	44	2.93*
DLPFC	10	L	20	-2.28*
			38	-2.28*

* $p < .05$

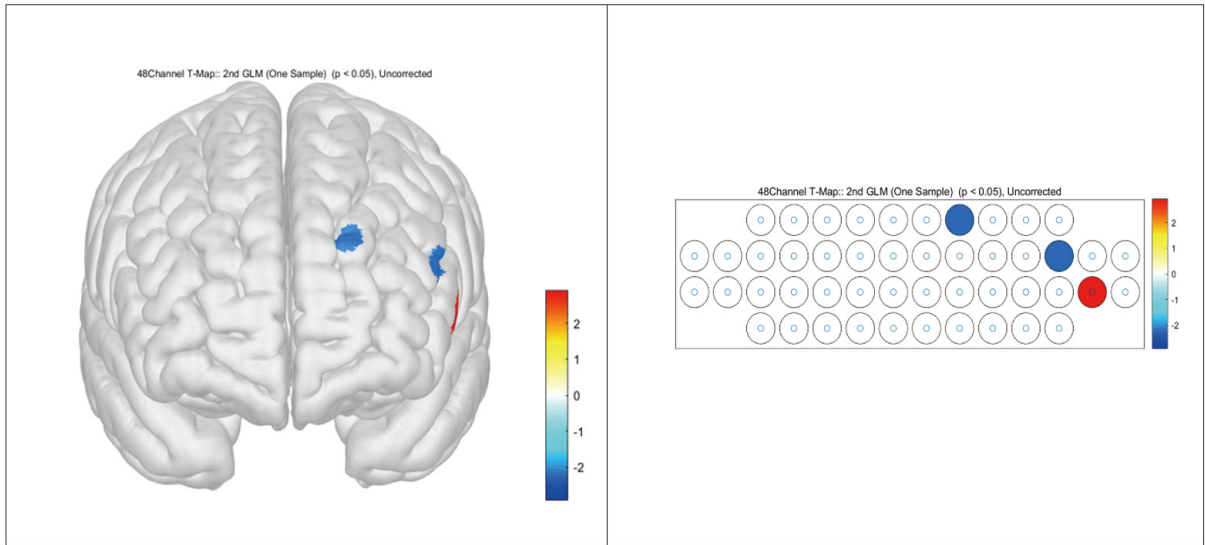


Fig. 5. The brain activation area in learning on the metaverse-based ecosystem

According to the previous study, when presented with visual tasks, the tendency of left-sided brain activity to be deeply related overall (Yoo et al., 2011) shows that brain activity is omnipresent on the left side due to the influence of visual materials such as various videos, photos, and images. In addition, considering the results of the study that the left VLPFC area is involved in the creation and understanding of language (Zhenhong et al., 2018), it can be interpreted that the metaverse task carried out in this study is related to the activity of conducting exploration activities by chatting with group members in groups of three. In this process, the students communicated with each other on the metaverse-based ecosystem platform and interacted with Metaverse Objects. During this process, it can be inferred that the activity of VLPFC domains related to receiving and comprehending linguistic information increased. In addition, the left DLPFC domain is responsible for overall cognitive activities and management, such as planning cognitive flexibility and working memory. It is known to be responsible for focusing and maintaining attention in problem-solving and task processes (Hertrich et al., 2021). Therefore, the decrease in activity in the area seen in this study can be interpreted as a decrease in learners' cognitive load due to providing various visual materials familiar to students during exploration activities using the metaverse-based ecosystem.

On the other hand, the left DLPFC region, which showed decreased activity, is a key area of the Central Executive Network (CEN). According to previous studies, it is mainly responsible for cognitive activity in the brain. This CEN region operates in an antagonism system with what is known as the Default Mode Network (DMN) (Bressler & Menon, 2010; Lieberman, 2013). In other words, if there is activity in the DMN region, there will be a decrease in the CEN region. From the results of this study, the left VLPFC region that is active when using the ecosystem metaverse is known as the DMN region (Seeley et al., 2007). In other words, it can be inferred that the increase in activity in the left VLPFC area when using the ecosystem metaverse led to a decrease in the activity of the left DLPFC area. It can be inferred that this is due to a decrease in the executive function of the DLPFC domain, which is related to processing cognitive information contrary to the task of communication and social activities related to interacting with objects.

Subtraction in Brain Activation for Zoom Compared to Metaverse

To analyze the brain areas that are significantly differentiated when conducting exploration using the metaverse-based ecosystem, the brain activity areas of ecosystem exploration using Zoom were subtracted and analyzed. As a result of the analysis, the brain activity in the brain activity area that was significantly differentiated in the ecosystem exploration using Metaverse was relatively low in the right OFC area corresponding to channel 16 and the left FP region corresponding to channel 41 (Table 3, Fig. 6).

Table 3. Subtraction result of brain activation for zoom-based inquiry compared to metaverse-based inquiry on ecosystem

Region	THREE	Hemisphere	Channel	t
OFC	11	R	16	-2.69*
FP	10	L	41	-2.23*

* $p < .05$

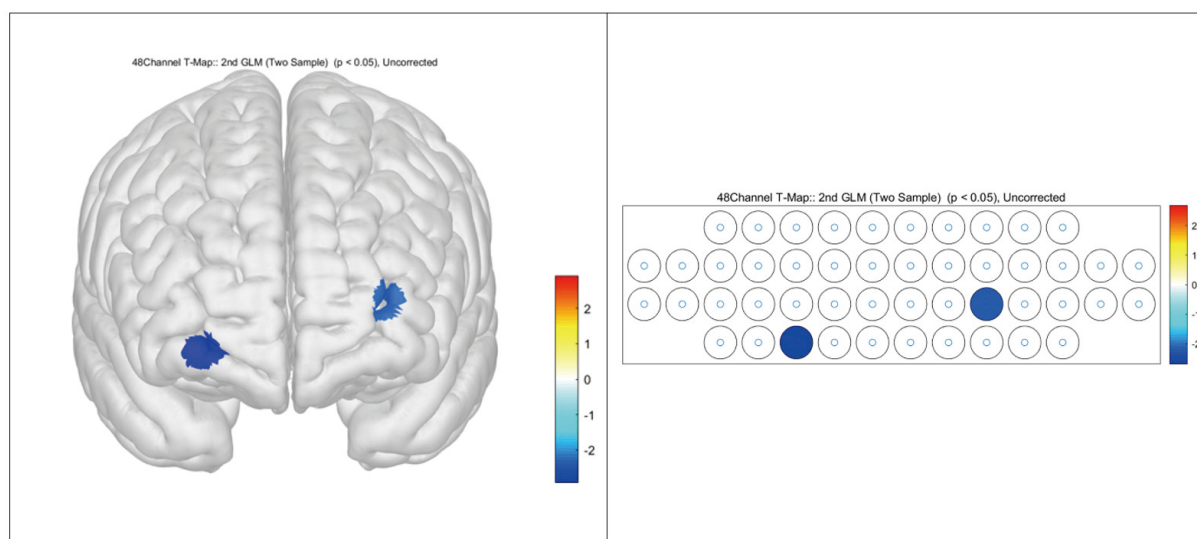


Fig. 6. The brain activation area in subtraction for zoom-based inquiry compared to metaverse-based inquiry on ecosystem

According to the results of this analysis, learners show relatively low activity in the right OFC area and the left FP area when exploring the ecosystem using the Metaverse compared to Zoom. The OFC area is known as the area related to systems such as emotion and motivation (Murphy et al., 2003). The left OFC domain is generally known to be related to motivational control, such as goal-directed behavior. In contrast, the right OFC domain is known to be involved in the handling of anxiety situations in prominent punishment cases (Adolphs, 2002). This area is activated when there is a high level of arousal, such as fear. It also increases activity when exposed to anxious situations (Eum et al., 2011; Min et al., 2022). Therefore, the brain activity results of this study show that negative emotions such as anxiety and worry appear relatively little in the definitional domain when using the Metaverse in the same task performance situation.

The left FP domain is active in exploratory decision-making processes (Koechlin & Htafil, 2007) and goal-directed thinking (Zajkowski et al., 2017). It can be inferred that the decrease in activity in this area when performing tasks using the Metaverse is less active in the goal-oriented thinking domain compared to the control tasks when using the Metaverse. This can be seen as a result of brain activity that supports the findings of previous studies on the Metaverse, which found that learners' high autonomy in the Metaverse can act as a factor that reduces learning when performing effective learning (Hyeon & Park, 2023) and that the placement of peer avatars in the Metaverse can act as a distraction factor to the learning material (Yang & Ryu, 2021).

Conclusions and Implications

This study measured and analyzed brain activity in metaverse-based ecosystem utilization using functional near-infrared spectroscopy (f-NIRS). The results of the study were as follows.

First, when middle school students were subjected to exploration activities using the metaverse-based ecosystem, it

was observed that the activity of the left VLPFC domain increased significantly, and the activity of the left DLPFC domain decreased significantly. In the Metaverse, there is a lot of interaction with objects and others, and in this study, three students worked as a group to conduct exploration activities. It can be inferred that as social interaction and communication progressed, the left VLPFC region, a related brain region, was activated. In addition, according to the previous study, the left VLPFC area activated in this study is the region included in the SN domain. It is also known that the activity of this region decreases the activity of the DLPFC region, which corresponds to the CEN region. As such, social interaction increased according to the characteristics of the Metaverse and tasks, and it can be said that the activity of the left VLPFC area, which is a related area, increased accordingly. On the other hand, since the activity of this area can also decrease the activity of the DLPFC area, which is the brain region responsible for cognitive functions, the decrease in the activity of the DLPFC area in the analysis of the overall brain activity area can be interpreted as a decrease in cognitive functions related to central executive function and working memory due to the increase in the activity of the VLPFC domain due to the increase in social interaction of exploration activities in the metaverse.

Second, when middle school students were compared with the brain activity of using the metaverse-based ecosystem and the non-face-to-face platform, it was observed that the activity of the right OFC area and the left FP area decreased significantly when the metaverse was used. The right OFC area is the area that is active when negative emotions such as anxiety or worry are present. In addition, when the survey and interviews were conducted after the students' activities, the results were confirmed to support the previous brain activity data. In the case of students who used the metaverse, they were more interested and had a lower level of difficulty than students personally felt about the difficulty of the task and the exploration activity. This means that when using the metaverse, compared to using a non-face-to-face platform, students are relatively more likely to conduct exploration activities based on positive emotions. The decreased activity in the left FP domain can be attributed to the low activity in the thought processes that trigger students' goal-directed thinking or metacognition when using the metaverse. Based on the results of the survey and interview after the students' exploration activities, it can be seen that when students use metaverse to conduct exploration activities, students can move around the Metaverse map autonomously and continuously observe the avatar movements of other students, so it can be seen that the activity of goal-oriented thinking to carry out the task is less due to distraction.

Based on the results of the previous study, the implications of this study are as follows.

First, based on neurological evidence, we identified the areas of brain activity that appear when middle school students use the ecosystem Metaverse. The neurological evidence for the differences in cognitive and definitional domains in the exploration activities using the Metaverse, which was previously suggested, was presented.

Second, when you are active in the Metaverse, you interact with objects and others, and the activity of related areas appears. When using the Metaverse, activation of brain regions related to social activities is seen. Therefore, it is necessary to ensure that appropriate communication activities can be carried out when conducting educational activities in the Metaverse.

Third, when using the metaverse, negative emotions such as anxiety are less likely to occur, and students can engage in activities based on positive emotions such as interest. If students who have a high level of anxiety or worry when performing learning tasks are presented through the metaverse, it is expected that they will be able to reduce negative

emotions and approach tasks with positive emotions.

Fourth, when using Metaverse, goal-oriented thinking can occur less. "The metaverse has some limitations, despite its reflection of many exciting elements." Even if students are given the same assignments, they think more quickly and are more interested in the metaverse. On the other hand, in the metaverse, students are given much autonomy and have environmental characteristics that can distract them from various stimuli. Therefore, goal-oriented thinking occurs less, which may lead to a decrease in the effectiveness of learning, so it is expected that it can be used as a tool for more effective exploration activities if it provides an environment where students can focus their attention in a more structured way considering the level of students when presenting tasks using Metaverse, and if challenging tasks and difficult tasks are provided.

Conflicts of Interest

The author(s) declared no conflicts of interest.

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