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The Effect of Problem-Solving Activities using Science Knowledge On the Resting-State Network of Brain

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Abstract

The purpose of this study was to investigate the effect of problem-solving activities using scientific knowledge on the resting network of brain. For this purpose, 16 high school students were asked to carry out scientific problem-solving activities. Before and after the activities, we measured the brain activity during the resting state, and we analyzed the change in the network. As a result, it was confirmed that the connectivity of the postcentral gyrus-limbic system-temporal lobe was increased after the activities. This result means that science problem-solving activities contribute to the linguisticization, working memory regulation, scene identification, intention of others, and stimulation of the reward circuit. The results of this study suggest that students' social development strategies should be considered along with existing strategies to improve their problem-solving abilities.

Keywords: *Scientific problem-solving activity, Resting-state network, Limbic-temporal network, Sociality*

1. Introduction

As our society becomes more complex and more advanced, to enhance the future competitiveness of the nation, the goal of future human resources development is set. In science education, the future talents must be equipped to improve various abilities, and many efforts are being made to improve creative problem-solving abilities. However, it is difficult to discover of the effectiveness of problem-solving activities in science education through a detailed analysis. Most of the studies that have analyzed the effectiveness of problem-solving activities were about changes in problem-solving abilities before and after learning; these studies quantitatively and qualitatively studied how the input group changed and how it changed [1]. However, there is a limit to developing innovative problem-solving learning models based on these studies.

So, how does one get a deeper understanding of the changes caused by problem-solving learning? Recently, some attempts have been made to apply neuroscience research methods to confirm the effectiveness of learning in science education. The brain plays a pivotal role in human thinking and action. In this process, each area of the brain functions in close connection with the others. These interregional functional connections can change depending on the individual's experience. Furthermore, physiological connectivity is also observed in the resting-state, during which the brain is not performing a specific cognitive activity. This is also reported to be changed by experience [2].

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Therefore, the effect of the science problem-solving activity can be examined through the change of the network of the resting period of the brain before and after the experience of the science problem-solving activity. In particular, studies using changes in the resting-state network do not require specific cognitive tasks in the process of measuring brain activity by using Functional Magnetic Resonance Imaging (fMRI). This method can compensate for the disadvantages of the conventional brain image measurement method, which is limited by task execution time, when studying cognitive processes that require a long time in task execution (such as problem solving).

2. Method

2.1. Procedure

To examine the effect of the science problem-solving activity through connectivity change of resting-state, the progress of the research process is shown below as [Figure 1]. We selected study subjects and composed learning activities. We applied the activities to the subjects, and scanned and recorded the resting-state functional images before and after. The functional connectivity changes in the resting state were analyzed based on scanned images. Through this, the effect of the science problem-solving activity was investigated.

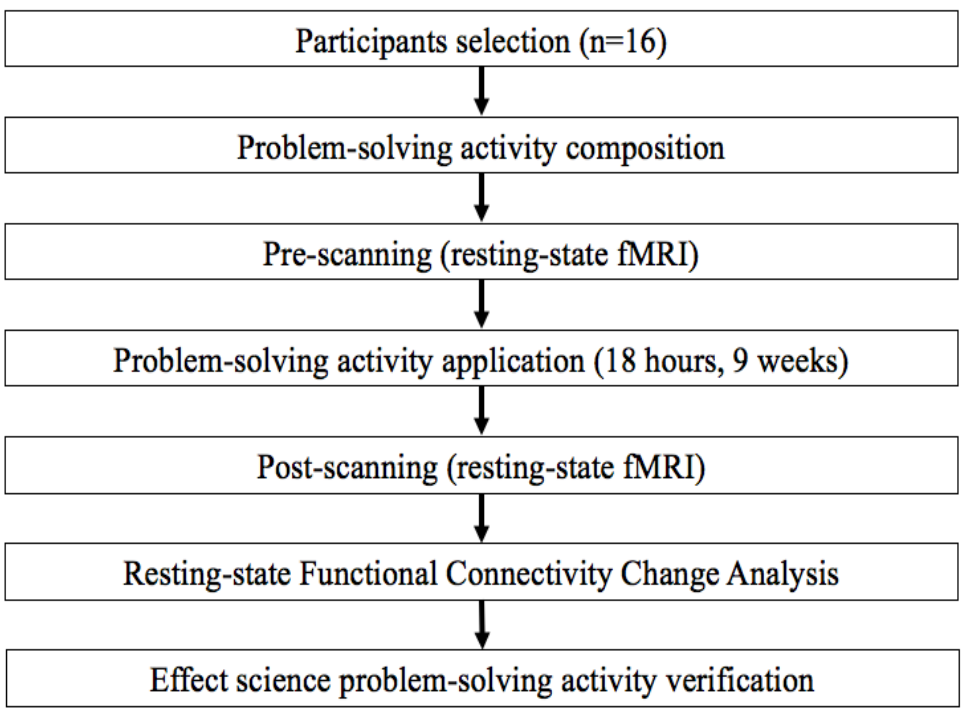

Figure 1. Research procedure

2.1. Participants and scientific knowledge-based problem-solving activities

Sixteen male students (16.38 ± 0.53) were selected from the second-grade students of Y high school in a central region of Korea. To control the bias caused by the unilateral brain, only the right-handed students were selected through the hand dominance test. Among the selected students, the results of psychiatric treatment, claustrophobia, drug use, and insertion of metal substances in the body were not found to be applicable. A total of 18 classes on science knowledge-based, problem-solving programs were applied to the students over nine weeks. A biomimicry centered convergence learning model [3] was selected and provided to subjects [Figure 2].

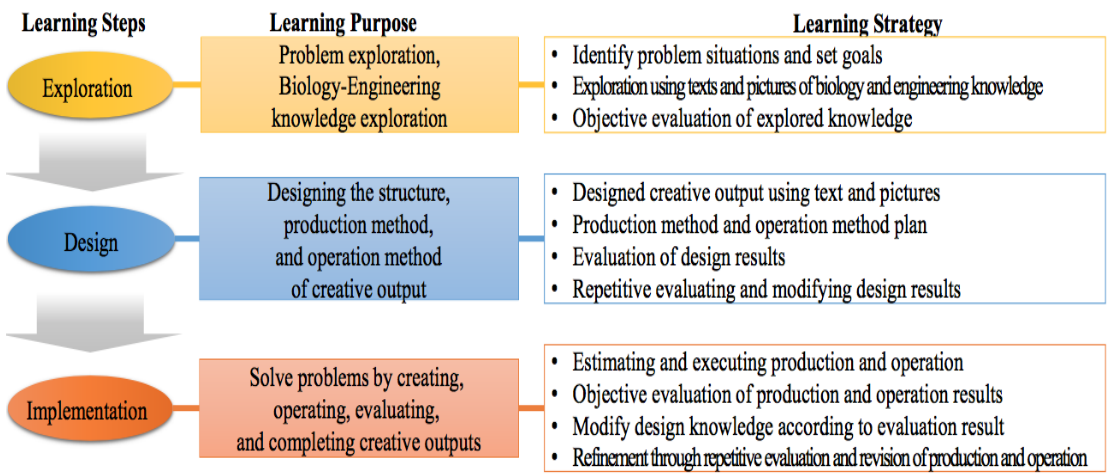

Figure 2. Biomimicry centered convergence learning model.

A biomimicry centered convergence learning model consists of three steps, 'Exploration', 'Design', 'Implementation'. In 'Exploration' step, the learning purpose is problem and biology-engineering knowledge exploration. In 'Design' step, the learning purpose is designing the structure, production method and operation method of creative output. In 'Implementation' step, the learning purpose is solving a problem by creating, operating, evaluating and completing creative outputs.

2.2. Imaging and analysis

The brain activation images were measured using a 3.0T MR scanner (Philips Achieva 3.0 TX) of the Human MRI Research Center, Ochang, Korea Basic Science Institute before and after the program treatment. The anatomical images were taken using the MPRAGE sequence, and the functional images were taken for three minutes using the EPI sequence (FOV: 200 mm, TR: 3,000 ms, TE: 35 ms). The collected images were preprocessed using SPM12 of Matlab 2016, and the resting-state network was analyzed using CONN 16.a. Each area of the FSL Harvard-Oxford Atlas and each area of the AAL atlas for the cerebellum was set as the region of interest. To investigate the effect of the program, the interregional correlation coefficient was calculated based on the BOLD value of the average time series of each area, the connection pairs that the its post-coefficient was significantly higher than the pre-coefficient were identified (FDR, $p < 0.001$).

3. Results and discussion

The following is a figure of the pairs of regions of interest that showed significantly higher resting-state connectivity after the experience than before the problem-solving activities using scientific knowledge [Table 1], [Figure 3].

As a result of the analysis, it was found that the connection pairs that showed significantly higher connectivity than before were the left caudate (Caudate l)-left anterior superior temporal gyrus (aSTG l), left Caudate–right temporal pole (TP r), left anterior superior temporal gyrus–left thalamus (Thalamus l), right accumbens (Accumbens r)-right Heschl's gyrus (HG r), left anterior middle temporal gyrus (aMTG l)-left pallidum (Pallidum l), and left postcentral gyrus (PostCG l)–right anterior temporal fusiform cortex (aTFusC r).

Table 1. ROI pairs with T-value, uncorrected p-value and FDR-corrected p-value of Brain network changed by problem-solving experience using science knowledge.

ROI pair in network	T-value	p-value (uncorrected)	p-value (FDR)
Caudate l - aSTG l	5.30	0.0000	0.0047
Caudate l - TP r	4.06	0.0005	0.0270
aSTG l - Thalamus l	3.90	0.0007	0.0370
Accumbens r-HG r	4.66	0.0002	0.0161
aMTG l - Pallidum l	4.65	0.0002	0.0167
aTFusC r - PostCG l	4.15	0.0004	0.0448

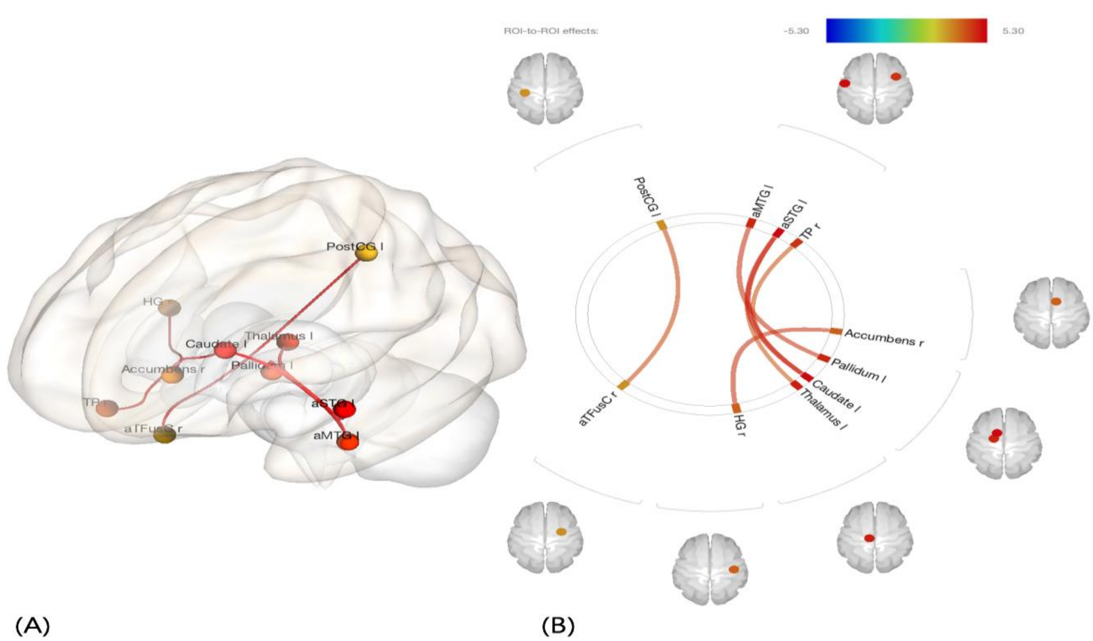

Figure 3. Brain network change by problem-solving experience using science knowledge. (A) 3d display of brain network, (B) Connectome ring of brain network

Through the connectivity of TP-Caudate-STG-Thalamus and MTG-Pallidum, the experience of the program shows that the grasp of the intentions in the presented situation, the motivation through the stimulation of the reward circuit, and the function of the inner language were enhanced [4][5][6]. In addition, as the connectivity of Accumbens-HG increased in the process of internal linguisticization, it seems that the activity of the motivation-reward region contributes to the effective performance of working memory [7]. Meanwhile, there are few preceding research studies on the connectivity of PostCG-ATFusC. The fusiform gyrus is involved in the function of grasping the intention of others, which is presented in the scene based on the recognition of the object presented visually [8]. The functions of PostCG related with mentalizing are basic motor learning and self-acceptance with a mirror neuron system that understands the behavior of others [9]. Therefore, the experience of problem-solving activities using scientific knowledge seems to lead to changes in brain functions that are goal setting by grasping the problems revealed in the scene, receiving feedbacks with mentalizing on others, motivating based on neural reward circuit, basically the cognitive function related to task execution (such as internal language generation and work memory activation).

4. Conclusion

The experience of problem-solving activities using scientific knowledge improves students' creative problem-solving abilities. To confirm the changes of these effects at the brain level, we analyzed the change of the resting network before and after the problem-solving activity experience. As a result, it was confirmed that the connectivity between the postcentral-temporal-limbic system was increased. This means that changes in the internal linguistic and working memory regulation ability, changes in the ability to grasp problems, understanding the intention of others, and improvements in learning motivation contribute to the improvement in problem-solving abilities. These results suggest that strategies for enhancing social skills that involve communicating with peers as well as existing strategies should be considered for problem-solving activities using scientific knowledge.

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