Why Do Most Science Educators Encourage to Teach School Science through Lab-Based Instruction?: A Neurological Explanation

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과학 교수·학습 과정에서 실험활동 중심 수업의 효율성에 대한 신경학적 설명

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적 요

현행 과학교육은 일반적으로 언어적 설명보다는 실험활동을 중심으로 수업을 진행하기를 권하고 있다. 더나아가 과학교육에 관련된 많은 연구들(예를들면, 학습성취도, 사고능력향상, 과학에 관련된 태도 등)도 이러한 실험활동을 중심으로 한 조작적 교수·학습 과정의 효율성에 대해서 지지해 왔다. 이렇게 과학교육에 대한 연구결과들과 실제 경험들이 학습자의 효과적인 학습을 위해서 실험활동 중심의 교수·학습 과정을 장려하고 있지만, 이들 연구들은 왜 실험활동 중심의 교수학습이 언어적 설명 수업보다 효과적인가에 대한 구체적인 설명을 제공해 주지를 못하고 있다. 본 연구는 이러한 의문에 대해서 최신의 신경학적 연구결과를 바탕으로 설명하고자 하였다. 최근의 신경학적 연구는 다중적 감각경로를 통한 정보의 전달이 단일적 감각경로를 통한 정보의 전달보다 신경세포 반응의 효율성과 반응시간의 신속성에 있어서 훨씬 효과적이라는 연구결과들을 제시하여 왔다. 따라서 이 연구결과를 과학학습에 적용할 경우, 실험활동 중심의 수업은 체감각-시각-청각적 감각경로를 통한 정보의 전달이 이루어질 수 있는 교수전략이고 언어적 설명 수업은 청각을 주로 활용하고 부분적으로 시각을 사용하므로, 신경세포 반응의 효율성과 시간의 신속성에 있어서 실험활동 중심의 수업이 훨씬 효과적이기에 실험활동을 통한 수업이 과학학습에 효율적이라는 설명이 가능하다. 이 가설을 테스트하기 위하여 본 연구는 비율추론과제의 해결에 실패한 중학교 학생 56명을 무작위적으로 두집단으로 나눈다음, 한 집단에게는 조작적 활동중심 피이드백을, 그리고 다른 집단에게는 언어적 설명 중심 피이드백을 제공하였다. 연구결과는 조작적 활동 중심 피이드백을 제공받은 집단이 언어적 설명 중심 피이드백을 제공받은 집단보다 통계적으로 의미있게 학습한 결과를 보여주었다. 따라서 본 연구는 실험활동 중심 수업의 효율성에 대한 신경학적 설명을 지지하는 증거를 제시하였다. 또한 이 연구는 연구결과의 교육적 활용을 위한 적용방안도 논의하였다.

Key words : 실험활동 중심 과학수업, 조작활동 중심 과학수업, 다중적 감각경로를 통한 정보전달, 신경세포의 반응, 비율추론과제

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I. Introduction

A long line of studies have claimed that, because science teaching through lab experiences is a useful strategy to develop students' cognitive abilities, science-related attitudes, scientific process skills, understanding the nature of science, and the acquisition of scientific concepts (Cho et al., 1989; Hofstein & Lunetta, 1982; Meichtry, 1992; Shulman & Tamir, 1973; Shutman, 1996), science class has generally been encouraged to be taught through lab-oriented instruction beyond traditional verbal-oriented instruction (Biological Sciences Curriculum Study, 1973; Cho et al., 1989; Korean Ministry of Education, 1994; Lee et al., 1997; National Curriculum Council, 1988; National Research Council, 1996). Further, visual presentations or demonstration lectures, rather than traditional verbal-oriented approaches, have also been supported as a valuable teaching-approach in learning science (Iddon, 1986; Mayer & Sims, 1994).

However, although these studies have shown the useful values of lab- or visual-oriented teaching in science, some interesting questions are raised from them. Those questions are 'why does teaching through lab-oriented approaches cause more effective outcomes in learning science than using verbal-oriented' s?' and 'why does teaching through visual presentations or demonstration lectures cause a significantly better learning in science class than verbal-oriented lecture?' Unfortunately, even the above studies (i.e., Cho et al., 1989; Hofstein & Lunetta, 1982; Meichtry, 1992; Shulman & Tamir, 1973; Shutman, 1996) have shown the positive outcomes of applying lab- or visual-oriented teaching into science classroom, they have little elaborated to answer for these questions. Therefore, because recent neurological advances have provided a clue to link these questions with neural activities, the present study was tried to answer for the questions based on the neurological advances.

According to the theory of limited neural activity (Grossberg, 1982), ideas/information activated in working memory require neural activity that decays at a constant rate. In short, what may be occurring during neural activity is that biological changes (e.g., increased myellinization or number of synapses) result in faster neural transmission, which allows for more information units to be held into working memory before decay becomes a problem. Thus, when a string of information units (e.g., random number) enters working memory, the string length is limited because the first item that enter begin to decay (i.e., start to be forgotten) while the later ones are being added. For mature adults the maximum number of separate information units that can simultaneously be held in working memory is about seven (Miller, 1956). However, for children and early adolescents, the number is less. Therefore, what we need to help learner is to produce more neural activity which is presumably effective in working memory and learning ability.

One way to promote neural activity may be provided by an effective sensory stimuli, such as stimuli with better quality and more quantities. Recent neurological studies have been suggestive of which one among those various sensory stimuli is more effective in neuronal information-processing (Benedesk, Pereny, Kovacs, Fisher-Szatmari, & Katoh, 1997; Blair & Thompson, 1995; Stein &

Meredith, 1993; Wallace, Meredith, & Stein, 1992; Wallace, Wilkinson, & Stein, 1996). According to these studies using non-human primates and cats, there have been found following substantial differences in the detection rates and reaction times of neural activities, which have, of course, been studied to be involved in cognitive functions, of those sensory stimuli which access the brain via multiple sensory channels:

First, these studies have shown that, when compared between single dimensional (e.g., visual, somatosensory, or auditory) and multiple dimensional (visual-somatosensory - auditory, visual-somatosensory, visual-auditory, or somatosensory-auditory) stimuli, neuronal detection rates and reaction time were significantly higher in multiples than singles. For example, detection rates were significantly higher and reaction times were significantly shorter to events that access the brain via multiple sensory channels when compared with reactions to their individual sensory components (c.f., Blair & Thompson, 1995; Hughes et al., 1994; Stein & Meredith, 1993; Wallace et al., 1992; Wallace et al., 1996).

Further, this multi-sensory effects far exceeded the simple summation of the separated ones of the multi-sensory stimuli. Formexample, the detection rate of combined stimulus composed of visual and auditory cues is more likely than the summation of the separated visual and the auditory cue. In parallel with this, reaction times to the combined stimulus are much faster than to the summation of two separated cues. Of course, three-dimensional (i.e., visual, somatosensory, and auditory) sensory input is the most effective one among four multi-sensory pathways (c.f., Stein & Meredith, 1993; see also Benedesk et al., 1997).

Also, multi-sensory effects far exceeded a simple summation of the same times of a unisensory stimulus. That is, the detection of combined stimulus composed of visual and auditory cues is more likely than either the two times of visual or auditory cue alone. Reaction time has also been shown faster in the combined multidimensional stimuli than the simple summation (c.f., Stein & Meredith, 1993).

In addition, visual-somatosensory modality among three bi-dimensional sensory inputs showed the most effective sensory pathway, and visual-auditory was the next. Among three uni-dimensional sensory inputs, visual was the most effective information-processing pathway. Next was somatosensory and the third was auditory pathway (c.f., Benedesk et al., 1997; Blair & Thompson, 1995; Stein & Meredith, 1993; Wallace et al., 1992; Wallace et al., 1996).

These results can strongly be suggestive of that teaching strategies used multi-diemensional sensory inputs are superior in learning science to the strategies used uni-dimensional seonsory inputs. That is, because the combined sensory pathway of visual, somatosensory, and auditory are much more effective in detection rates and reaction times than visual or auditory alone, or visual-auditory sensory pathway, teaching strategies used visual-somatosensory-auditory presentations may be more effective in learning science than visual or auditory alone, or auditory-visual presentations.

How can we apply these suggestives to teaching science? Notice presentation modes of teaching science used in our classroom. Some classes apply verbal-expository teaching modes and others apply manipulative (or lab-activity) teaching modes into their science classrooms. Again, notice sensory pathways used in verbal and manipulative teachings.

Verbal teaching strategies presumably use presentations composed of mainly auditory and a little visual sensory pathways. However, manipulative teaching strategies presumably used combined presentation modes composed of visual, somatosensory and auditory sensory pathways.

Therefore, the purpose of the present study is to test hypothesis that teaching strategies using three-dimensional sensory pathways are more effective in learning science than uni- or two-dimensional' s.

II . Methodology

1. Design

In the present study, teaching modes of three-dimensional sensory inputs were manipulative teaching strategies and teaching modes of two-dimensional sensory inputs were verbal teaching strategies. Fifty-six students who failed to successfully solve two proportional reasoning tasks (i.e., the pouring water tasks) were sampled for this research from a junior high school. The subjects were randomly divided into a manipulative or verbal teaching group.

The manipulative group was given testing and manipulative tutoring on the use of proportional reasoning strategies in a test of proportional reasoning, while the verbal group was given testing and verbal tutoring. Age and cognitive abilities measured by the Group Embedded Figure Test, the Tower of London Test and the Wisconsin Card Sorting Test were showed no statistically significant difference between two groups. [See Kwon (1997) for a review of these instruments]. However, verbal group showed a significant higher performance on the Figural Intersection Test than manipulative' s. Performance on eight proportional reasoning tasks during instruction was used as the dependent variable. If multi-dimensional hypothesis that teaching strategies using three-dimensional sensory pathways are more effective in learning science than uni- or two-dimensional' s is right, then manipulative teaching group' s performance on proportional reasoning test should be higher than verbal teaching group' s. This study was investigated by post-test only control group design without pretest session, because all subjects who failed to successfully solve two proportional reasoning tasks were sampled as a homogeneous group prior to tutoring .

2. Subjects

Fifty-six (56) students who failed to use proportional reasoning strategy in the Pouring Water Tasks (Suarez & Rhonheimer, 1974; Lawson, 1978) were sampled as subjects from total 126 male students.

The subjects were in eighth grade from a junior high school in Korea, which was located in a university town of approximately twenty thousand people. These subjects ranged in age from 13.08 to 15.17 with a mean age of 13.93 (SD = 0.48). Then, the selected subjects were randomly classified into one of two teaching groups, manipulative and verbal teaching groups.

3. Proportional Reasoning Test Instrument

Subject' s ability to use proportional reasoning strategies was measured by the Test of Proportional Reasoning (TPR). The TPR consists of the following 8 items: 1) two from the Cuisenaire Rod Walls Task (Lawson & Wollman, 1980); 2) two from the Pouring Water Task (Suarez & Rhonheimer, 1974; Lawson, 1978); 3) two from the Piagetian Balance Beam Task (Inhelder & Piaget, 1958); and 4) two from the Coupled Gear Task (Lawson & Wollman, 1980).

The Cuisenaire Rod Walls Task (Lawson & Wollman, 1980) uses two kinds of rods which differ in color and length. The white and the red rods are one and two units in length, respectively. The subjects were asked to predict how many of one kind of rod would equal in length a specified number of another size of rod. For example, subjects were asked to predict how many white rods were needed to equal the length of four red rods. To complete these tasks successfully, subjects must use the proportion reasoning strategy.

In the Pouring Water Task (Suarez & Rhonheimer, 1974; Lawson, 1978), two plastic cylindrical containers of equal height but with different diameters were used and the subjects were asked to predict how high a given quantity of water that occupies 6 units in the wide container would rise if poured into the narrow container.

The Balance Beam Task (Inhelder & Piaget, 1958) uses a balance beam and hanging weights and tests the ability of the subjects to balance various combinations of weights at various locations along the beam. For example, given a 10-unit weight on 5 units of length from the fulcrum, the subject is asked to predict the proper location of a 5-unit weight to balance the beam. It is assumed that the subject would use proportional reasoning strategy to complete this task successfully.

In the Coupled Gear Task (Lawson & Wollman, 1980), the subject was asked to solve the ratio of disk rotation. In this task, two plastic disks with different diameters and axes were coupled. When one disk was rotated, the other disk would rotate as well, but fewer or more times, depending on the ratio of the disks diameters. Using information (e.g., the smaller disk rotates 12 times while the larger disk rotates 8 times), the subject was asked to predict how many times one disk would rotate given the other disks specified number of rotations.

The correct use of the proportional reasoning strategy for each task following tutoring was used as the dependent variable in this study. The subjects response on each task was scored on a 0-1 scale: 0 points for an incorrect use or no attempt to use proportions and 1 point for a successful solution using proportional reasoning strategy. The total number of correct responses was analyzed as the dependent variable of subjects acquisition of the proportional reasoning strategy during instruction. In this study, Cronbach' s alpha of the test was 0.67.

4. Tutoring Procedures

The subjects who failed the two Pouring Water Tasks were randomly classified into one of two tutoring groups. One group was tutored with active manipulation of physical materials to check subject' s predictions for proportional reasoning tasks. For example, subjects in the manipulative group were first asked to predict the answer for a proportional reasoning task. Then, they were asked to manipulate physical materials to obtain actual results and compare these results with their predicted results. At this point the symbolic notation of the a/b = c/d proportion to organize data was introduced. Other tasks were also given using the same testing-tutoring procedure. That is, tutoring sequences were administered as following: Pose a Cuisenaire Rod Wall Task → tutor → pose another Cuisenaire Rod Wall Task → tutor → pose a Pouring Water Task → tutor → pose another Pouring Water Task → tutor → pose a Balance Beam Task → tutor → pose another Balance Beam Task → tutor → pose a Coupled Gear Task → tutor → pose another Coupled Gear Task. The tutorials were given on a one-to-one basis. The other group was given a series of verbal tutorials about proportional reasoning strategies to check their predictions. For example, subjects in the verbal group were asked to predict an answer for a proportional reasoning task. However, they were given verbal feedback of the results (i.e., the researchers solution using proportional rule), rather than gaining the actual results through active manipulation of materials. That is, subjects in the verbal group were given verbal information on how to use the a/b = c/d proportional rule in each of tasks. Tutoring sequences of verbal group were the same as that used for manipulative group.

5. Manipulative Tutoring

Each subject in the manipulative group met the researcher for a series of four 30 minute feedback tutoring sessions, in which the subject actively manipulated the physical materials for each task.

Cuisenaire Rod Walls Task. This session involved the use of white and red rods, each represented a different length of rod. Initially, subjects constructed 'a wall' made up of two white rods placed on top of one red rod (2:1). Next to this wall, a row of four red rods was then constructed, and the subject was asked to predict how many white rods would go with the four red rods to complete the longer wall of similar proportions. The subject was then allowed to construct the wall to check the prediction with direct manipulation of the materials. At this point the symbolic notation a/b = c/d (2:1 = x:4) was also introduced. The notation was written next to the rods to demonstrate its relationship to the rod walls. Hence these tutoring sessions involved manipulative feedback, using physical materials that demonstrated proportional relationships and the language used to describe these relationships. After this feedback, the subject was asked to predict how many red rods would be needed on top of 9 white rods to complete the wall? The subject was allowed to construct the wall to check his/her prediction with direct manipulation. Again the symbolic notation a/b = c/d (2:1 = 9:x) was then introduced.

Pouring Water Task. The tutoring for this task involved the use of two plastic cylindrical containers with the same vertical scale marked on each, but different diameters. Given equal volumes of water for each cylinder, the ratio of the heights of water was 3:2. Subjects observed an initial demonstration of water at a height of 4 units in the wide cylinder being poured into the narrow cylinder to a height of 6 units. Water was then poured into the wide cylinder at a height of 6 units. The subjects were asked to predict how high the water would rise when these 6 units of water were poured into the narrow cylinder. After predicting, the subjects were allowed to pour the water and note the physical relationship.

Then, the symbolic notation a/b = c/d (4:6 = 6:x) was introduced. Then, the subjects were given a similar task to solve. Water was poured into the narrow cylinder up to the 11th mark and the subjects were asked to predict how high the water would rise when it was poured into the empty wide cylinder. After their predictions were made, the subjects were allowed to pour the water and note the physical relationship. Then, the symbolic notation a/b = c/d (4:6 = x:11) was introduced to the subjects.

Balance Beam Task. A balance beam and hanging weights were used for this task. Initially, the students were asked to predict where a 5-unit weight should be hung to balance a 10-unit weight which is hung 5 units of length from the fulcrum. To check their predictions, the subjects were allowed to hang the 5-unit weight on the beam and, if need be, move the weight incrementally until a balance was achieved. Following this procedure, the symbolic notation WL = W' L' (10×5=5×L') was introduced to the subjects.

Then, the subjects were given a similar task to solve. Subjects were asked to predict where a 5-unit of weight must be hung on the beam to balance two 2-unit weights which were hung 2 units and 8 units of length, respectively, from the fulcrum. After predicting, the subjects were allowed to hang the weight at the predicted location and, if need be, move the weight incrementally until a balance was achieved. After achieving the balance, subjects were given the symbolic notation WL = W' L' ([2× 2] + [2×8] = 5×L')

Coupled Gear Task. A set of coupled gears was used during this tutoring session. The gears differed in size in a ratio of 4 : 6 (small : large gears), 3 : 6 (small : new gears), and 4 : 3 (large : new gears). Turning a single shaft would rotate also the gears and individual gears would be uncoupled so that only two gears would rotate. Initially, a subject observed two gear rotation: eighteen rotations of the small gear produced twelve rotation of large gear. Then, the subjects were asked to make a prediction based on the following question: If the small gear was rotated sixteen times, how many times would the large gear rotate? After predicting, the subjects were asked to turn the shaft to rotate the small gear sixteen times, while simultaneously counting and recording the number of times the large gear rotated. The subject would observe that, when the small gear rotated sixteen times, the large gear rotated 10 2/3 times. Then, the ratio notation that two rotations of the large gear produced three rotations of the small gear would be introduced. After obtaining the ratio of 2 : 3, the symbolic notation a/b = c/d (i.e., 2/3 = x/16) was introduced. After the tutoring, the subjects observed again two gear rotation: twelve rotation of the large gear produced nine rotation of the new gear. Then, the subjects were again asked to make predictions for the following task: If the new gear were rotated 26 times, how many times would the small gear rotate? After predicting, the subjects would be asked to make the new gear rotate 26 times and record the number of rotations the small gear made. At this point, the symbolic notation a/b = c/d (i.e., 2/1 = 26/x) was also introduced to the subjects.

6. Verbal Tutoring

The subjects in the verbal tutoring group were also individually tutored for the same tasks and time duration as those of the manipulative group. The verbal group was also given the same tutoring procedure as, but the different teaching strategies from the manipulative group. The subjects in the verbal group were not allowed to manipulate the physical materials. Only pencil and paper, and verbal instruction were used during the tutoring sessions for the verbal group subjects.

III. Results and Discussion

This study investigated the mean score differences between manipulative and verbal groups' performance on a proportional reasoning test. Table 1 shows the results of t-test analysis between two groups, which students' abilities to use proportional reasoning strategies during tutoring were significantly different between manipulative and verbal groups. As you can see in Table 1, mean scores of manipulative and verbal groups were 4.13 (SD = 1.91) and 3.00 (SD = 1.55), respectively.

Central hypothesis tested in the present study was that alternative teaching strategies used multi-dimensional sensory inputs facilitate more shift from the non-use to the use of the advanced reasoning strategies than less-dimensional's. In the present study, there was no significant difference in age, inhibiting ability, planning ability, and disembedding ability between manipulative and verbal groups. Further, verbal group showed a significantly higher performance in mental capacity than manipulative's. In spite of no significant difference between both group's cognitive abilities, manipulative group's performance on the test of proportional reasoning during instruction showed statistically significant higher performance than verbal group's ($t = 2.45$, $p < 0.02$). Therefore, the manipulative group's higher performance was a neurological explanation for the question why lab-activity-based instruction is more effective in learning science than verbal-based instruction. Lab-activity-based instruction applies primarily alternative teaching strategies using three-dimensional sensory input which is more powerful way in neuronal activity processing than uni- or bi-dimensional sensory input applied in verbal-based instruction.

IV. Conclusions and Implications

In conclusion, because manipulative group's performance on the test of proportional reasoning during instruction showed statistically significant higher-performance than verbal group's, the present study supported the hypothesis that alternative teaching strategies using multi-dimensional sensory inputs facilitate more effectively learning science (i.e.,

Table 1. Ability to use proportional reasoning strategies by instruction

Group	N	Mean Score	SD	t-value	p
Manipulative	30	4.13	1.91	2.45	0.017
Verbal	26	3.00	1.55		

the shift from non-use to the use of advanced reasoning strategies in the present study, in the present study) than other teaching strategies using less-dimensional' s.

Findings of this study are suggesting several implication for instruction designed to improve students' learning science. An important contribution of the present study involves finding significant roles of alternative teaching strategies using multi-dimensional sensory input in teaching science. Based on the present results, science instruction for developing students' scientific concepts and reasoning ability should be oriented to teaching strategies using multi-dimensional (e.g., visual-somatosensory -auditory) sensory input.

One of the teaching strategies using visual-somatosensory-auditory sensory input can be applied into manipulative teaching or lab-based instruction in science class. Bruner (1965) has also argued that an effective instruction should be provided by an integrative representing of somatosensory, visual and verbal information units. According to Bruner, human beings construct models of their world through three systems of processing information (i.e., action, imagery and language). Bruner used the terms enactive, iconic, and symbolic to identify these modes of representation. In the enactive mode, the information is presented to the student in such a way that he can act upon it directly and transform the materials involved in the learning process. The iconic mode is characterized by materials which visually represent the information, but the materials cannot be directly manipulated. The symbolic mode is characterized by manners which is presented with the information in a verbal. Then, Bruner concluded as an effective instruction is heavily relied on the successive emergence of action, image, and word as the vehicles of representation. The manipulative teaching in science lab (or lab-based instruction) applied as a mode of tri-dimensional sensory input in this study can be one of powerful representing modes to provide the successive emergence of action, image and word, because student uses somatosensoty, visual and verbal sensory inputs in the manipulative teaching environment.

However, verbal instruction or screen-visualized instruction uses verbal-visual representing or visual-verbal representing, which is presumably less effective in the successive emergence of action, image and word. Therefore, students in science classroom should be fostered to participated in manipulative activities including somatosensory-visual-verbal information input for an effective learning.

Further, the present study seems like to suggest benefits of manipulative instruction over demonstrative instruction as a teaching strategy for helping students learn scientific concepts and reasoning. As described in the present paper, information pathways in manipulative activity include somatosensory, visual and auditory sensory inputs. However, information pathways in demonstration use almost visual and auditory sensory inputs. Somatosensory information input is little (probably not) used in demonstration (or screen-visualized presentation). A recent study conducted by Druyan (1997) also provided an evidence to support the idea of the effectiveness of manipulative teaching. That is, Druyan showed that kinesthetic (i.e., manipulative)-oriented feedback was found to be more efficient strategy in promoting the cognitive conflict on the conceptual change of balance and speed in children than visual-oriented feedback. According to her data, kinesthetic feedback made progresses of 80 and 75 % of the participants in the conceptual change of balance and speed, respectively. However, demonstration feedback made progresses of 45 and only 8 % of the participants in the conceptual change of balance and speed, respectively. Therefore, when other teaching variables are controlled, the present study is suggesting of which manipulative instruction may be more effective way of teaching strategy in learning science than demonstration instruction.

ABSTRACT

The purpose of the present study was to test hypothesis that, because it uses tri-dimensional sensory pathway which have been showed a higher rate of neural activities than uni- or bi-dimensional's, lab-activity-based instruction is more effective teaching strategy in learning science than verbal-based instruction. In the present study, manipulative teaching strategy that uses visual, somatosensory and auditory information pathway was regarded as a mode of tri-dimensional sensory inputs. In addition, verbal teaching strategy that uses mainly auditory and a little visual information pathway was used as a mode of bi-dimensional sensory inputs. Fifty-six students who failed to successfully solve two proportional reasoning tasks (i.e., pouring water tasks) were sampled for this research from a junior high school. The subjects were randomly divided into a manipulative or a verbal teaching group, and given manipulative or verbal tutoring on the use of proportional reasoning strategies and a test of proportional reasoning during instruction. The results showed that manipulative group's performance on the test of proportional reasoning during instruction showed significantly higher performance than verbal group's ($t=2.45$, $p<0.02$). The present study also discussed some educational implications of the results.

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