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Golgi and Cajal's scientific inquiry processes on the Neuron

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<ABSTRACT>

Adopting history into biology inquiry can shed light on the research life of biologists and the inquiry footsteps they had stridden. This attempt also can be the effective alternative of scientific inquiry teaching, which has been appreciated by a volume of previous studies. This study focuses on an interesting story of Golgi and Cajal, both the laureates of 1906 Nobel Prize. The most important reason this topic is chosen is because students meet Golgi and Cajal's study results in their textbooks. The purpose of this study is to establish a teaching framework adapting the inquiry process done by Golgi and Cajal into biology inquiry learning at the level of secondary school biology content. To meet the goal, this study briefly introduces the scientific inquiry process first, reviews two biologists' inquiry history, and then analyzes their inquiry with the respect to the scientific inquiry process. Based on this analysis, at the end of this paper is proposed a possible teaching worksheet in order to facilitate the practice of guiding students' biology inquiry adopting biology history.

Key words: The history of biology, Scientific inquiry process, Golgi, Cajal, Teaching and learning method

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Ⅰ. Introduction

Learning how to do biology inquiry is the main topic of biology education. Students can relate themselves to the biological content knowledge when they participate in the inquiry process, directly exploiting scientific process skills. This enables students to lower barriers to the knowledge and improve inquiry-associated skills(DebBurman, 2002). Inquiry commonly involves five steps; observation and classification, generating scientific questions, establishing the hypothesis, designing experiments, and evaluating posed hypothesis. This process offers students the opportunity of becoming scientists. Scientists do this on a daily basis, repetitively, and incessantly.

Most knowledge of school biology was developed and stabilized decades or centuries ago, which means biologists originally studied and even dedicated themselves to what contemporary students 'easily' learn in the class. Nevertheless, biologists and their research processes tend to be disconcertingly overlooked (Hershey, 1991). A few early studies are mentioned in passing, but little else regarding the development of biology is addressed in current textbooks compared to the textbooks about a century ago (Eichman, 1996). This may have been the result of the drastic increase of biology content knowledge with history becoming the first casualty. Students lost the chance to view the biology as a story-like, progressive, attractive process. Biological knowledge is merely static to them.

Here, the history of biology means the historical background material including persons, places, events, ideas and experiments of the past (Eichman, 1996). Adopting history into biology inquiry can shed light on the research life of biologists and the inquiry footsteps they had stridden. This attempt also can be the effective alternative of scientific inquiry teaching, which has been appreciated by a volume of previous studies. DebBurman (2002) showed that learning the history of relevant scientific knowledge accelerates critical thinking skills and the understanding of scientific research behind textbook knowledge in advanced undergraduate students. Hendrick (1991) proposed introducing history into the teaching of science as one of the best ways to communicate both the substance of science and the problems in doing science.

This study focuses on an interesting story of Golgi and Cajal, both the laureates of 1906 Nobel Prize. The most important reason this topic is chosen is because students meet Golgi and Cajal's study results in their textbooks. When they learn the cell, the Golgi apparatus appears. When learning central nerve system, the story starts from neurons and synapses. Therefore, the story of Golgi and Cajal is worth investigated.

Golgi contributed to the early study on the nervous system structure. He developed the staining method, black reaction. He discovered golgi apparatus, golgi

tendon organ. On the other hand, with his observation on the sophisticated nerve structure, he had misinterpreted on the structure of nerve system as a continuous reticular network. Rather, Cajal declared that the nerve system is composed of the special individual cells, now called neurons. Cajal employed Golgi staining method and saw almost the same figure with Golgi's one. They made different conclusions from the same process. This is another reason the current study pays attention to the Golgi and Cajal story. Introducing this to students, they can look through inquiry steps and recognize the importance of right conclusion and the influence of scientists' perspectives on the study results.

The purpose of this study is to establish a teaching framework adapting the inquiry process done by Golgi and Cajal into biology inquiry learning at the level of secondary school biology content. To meet the goal, this study briefly introduces the scientific inquiry process first, reviews two biologists' inquiry history, and then analyzes their inquiry with the respect to the scientific inquiry process. Based on this analysis, at the end of this paper is proposed a possible teaching worksheet in order to facilitate the practice of guiding students' biology inquiry adopting biology history.

Ⅱ. Literature Review

1. The process of scientific inquiry

Kwon et al. (2008) demonstrated that the process of scientific knowledge generation is common in four fields of science, physics, chemistry, earth science, and biology as followed table 1. This is based on the analysis of the overall inquiry process conducted by previous scientists. The first phase is the observation mainly done in an inductive manner. Scientists develop and accumulate observation and questions. To solve the questions, they design how to observe organized, and then observe further. Passing this first phase, scientists move on the second phase of causal questions generation. Causal questions are the explanation on the cause of the phenomena, which proceeds to the third step of hypothesis generation. Causal questioning and hypothesis generating are both relevant to the abduction. Abduction occurs when hypothesis is posed to explain the questioning situation from the similarly experienced previous situations. Shortly, the experience is 'abducted' to explain the current questioning situation (Kwon et al., 2008). The fourth phase is formulating the experiment to test the hypothesis. This process follows the hypothesis; therefore, it is based on the deductive process that undergoes the investigation of given hypothesis. Along the experimental implementation,

researchers stretch to the final phase of hypothesis evaluation where hypothesis becomes acknowledged or denied.

This process is common in scientific inquiry. Students will benefit from being aware of this process and wielding it in their inquiry. They also learn how to learn because this is one of a knowledge generation process.

<Table 1> Scientific inquiry process

Reasoning scheme	Inquiry process	Detailed process
Induction	Observation	Simple observation
		Operative observation
		Commonness discovery
		Classification
		Pattern discovery
		Hiararchy discovery
Abduction	Causal Questioning	Generating Causal questions
	Hypothiesis generation	Analyzing question situation
		Identifying experienced situation
		Generating hypothetical explanations
Deduction	Inventing method and criteria	Inventing test method
		Inventing criteria for evaluation
	Evaluating hypothesis	Collecting result
		Evaluating hypothesis and Stating conclusion

2. The study of Golgi and Cajal

Camillo Golgi (1843-1926) was an Italian physician and Ramon y Cajal (1852-1934) was a Spanish neuroanatomist. Previous studies before Golgi and Cajal emerged are shown in table 2. Also, the table 3 lists events chronologically relevant to the nervous system studies around the time Golgi and Cajal appeared in the history of neurology.

<Table 2> Previous studies before Golgi and Cajal emerged

B. C. 460~370 Hippocrates asserted the brain is the origin of intelligence. With the data collected by his mentors, Alcmeaeon and Anazagoras, he hypothesized that the epilepsy comes from the malfunctioning brain.

B. C. 384-322 Aristotle discovered that the chicken could walk around without its head and that the heart was still warm after death but the head was cold. With these observations, he concluded the heart is the center of the body and the brain is just the cooler of one's excitement, fervor, and spirit. This

perspective had sustained for several centuries.

130-200 Claudius Galen discovered that the brain has three ventricles or 'cells' in which one's mind is located, but the other parts of brain is not important according to the clinical observation.

1514-1564 Andreas Vesalius observed many animals had similar ventricular systems to those of humans. He considered that the ventricles did not house the human soul.

1596-1650 Rene Descartes suggested the mind-body dichotomy which says they are separated from each other. He argued that the mind and body can interact through the pineal gland.

1621-1675 Thomas Willis spelled out a role of the cortex in higher cognitive functions like memory through comparative anatomy. He wrote in his textbook that the convolutions of cortex are far more numerous and rare in man than in any other animal because of the variety and number of acts of the higher faculties. Also, he stated the corpus callosum as the center of imagination.

1758-1828 Frantz Josef Gall studied the localization of mental function in the brain. He developed cranioscopy, renamed to phrenology by his follower Johann Spuzheim. Cranioscopy or phrenology examines the shape of the skull as the presentation of the personality.

1824-1880 Paul Broca discovered the left frontal region is responsible for articulated language with the patients who contained the lesion in a particular part of the cortex.

1848-1905 Carl Wernicke asserted that not all language deficits are related to the Broca's area. Damages to the left posterior, superior, temporal gyrus resulted in deficits in language comprehension.

<Table 3> The Chronology of nervous system study

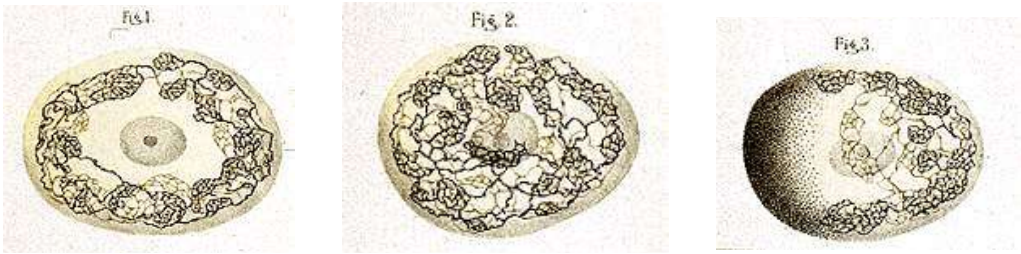
1791 Luigi Galvani discovered electrical nerve impulse.
1838-1839 the cell theory: The cell theory that tissues are composed of cellular elements had been enunciated in 1838-1839 by Mattguas Jacob Schleiden and Theodor Schwann, but had not been extended to the nervous tissue.
1850 Emil Du Bois Reymond measured nerve impulse at the hinder leg of the frog.
1873 Golgi's staining method developed
1878 Golgi described the tendonous sensory corpuscles
1886-1892 Golgi provided fundamental contributions to the study of malaria

1887 Cajal meets the Golgi staining method
1889 Cajal shows the axon contact supporting neuron doctrine
1891 Wihelm waldeyer announced the neuron doctrine. Waldeyer christened the nerve cells as "neurons"
1898 Golgi apparatus was discovered.
1900 Charles Sherrington named the axon contact as a synapse
1906 Golgi and Cajal share the Novel Prize in Physiology or Medicine in 1906

1) The study of Golgi

Camillo Golgi and Ramon y Cajal shared the Nobel Prize in Physiology or Medicine in 1906 in recognition of their contribution on the structure of the nervous system. Golgi's staining method developed in 1873 was widely used to studies of the cerebellum, the olfactory bulb, hippocampus and the spinal cord. He published a short note, 'On the structure of the brain grey matter', in 1873 in which he described that he could observe the elements of the nervous tissue "studying metallic impregnations after a long series of attempts" (Bentivoglio, 2011). Cajal, a proponent of this method, mainly used the Golgi staining and Ehrlich's methylene blue stain, although he was against the reticular theory of Golgi (Grant, 2006)

When Golgi attempted to stain the nervous tissue, prevalent staining method at that time did not work. Golgi tried metal impregnation of nervous tissue, using mainly silver, which could stain a limited number of cells, about 1-10% of neurons, in an arbitrary manner. This enabled him to view the paths of nervous tissues in the brain for the first time. Otherwise, all structures would be seen but only an overcrowded jungle. Golgi called his selective staining technique the 'black reaction' and later named it Golgi's method or Golgi stain. Also, Cajal could discover doses of novel facts about the organization of the nervous system with the Golgi staining method. Cajal improved the technique by double impregnation. The classical Golgi impregnation method is very elegant in its simplicity. With this quintessential way of staining, Golgi could investigate the nervous tissue and concluded that the tissue is a reticular network of continuous elements, which was proven not to be correct. Golgi believed that ramified nerve fibers could back the 'reticular theory', which elaborated that the nervous system was forming an complicated network and that the nervous impulses stretch along that network" (Bentivoglio, 2004).



<Figure 1> Golgi's drawing of the internal reticular apparatus of the spinal ganglia cell (Mazzarello, 1996)

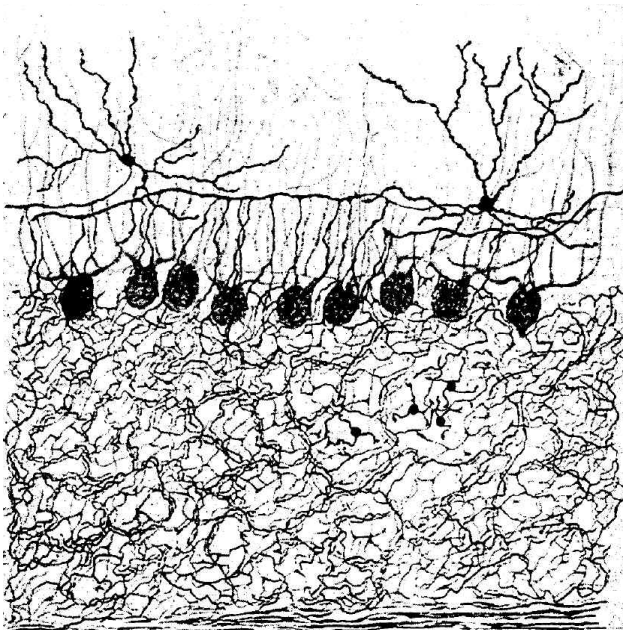
Meanwhile, with his own staining method under his light microscope, the Golgi apparatus was found in the nerve cells [Figure 1]. It was identified in 1898 by Golgi. It processes and packages proteins before they head to their destination or secret to outside the cell. The Golgi apparatus, one of the first organelles ever observed, forms a part of the cellular endomembrane system. At that time, the existence of cellular endoplasmic membrane system was not accepted widely because most biologists thought it was from the error of observation. Far later in 1950s, the Golgi apparatus was eventually confirmed. In the article 'Life and discoveries of Camillo Golgi', Bentivoglio states as followed;

> *Golgi was an exceptionally acute and prolific investigator, who provided a number of outstanding observations. Although he misinterpreted the overall view of the organization of the nervous system, he contributed highly to the modern knowledge of its structure. Among other findings, Golgi described the morphological features of glial cells (that are also impregnated by his staining) and of the relationships between glial cell processes and blood vessels. He also described two fundamental types of nerve cells, still named after him as neurons 'Golgi type I', extending their axons at a distance from the cell body and 'Golgi type II', with axons ramifying in the vicinity of the cell body.*
> (Bentivoglio, 2004)

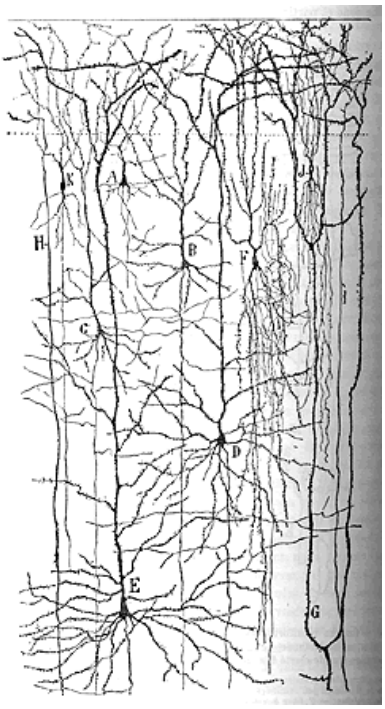
Golgi and Cajal, the co-laureates of Nobel Prize in 1906, met just one time to receive the award. They both gave lectures, then the styles were so different. Golgi tried to convince audience the reticular neural networks and only succedded to be imprinted being out-of-date. Cajal, in a businessperson-like manner, praised Golgi's accomplishment, briefly demonstrated the contiguity (not continuity) of individual cells, and then moved on the introduction of his ongoing study on nerve degeneration and peripheral nerve system(Bentivoglio, 2004).

There may be the personality difference between Golgi and Cajal. Golgi was coolly academic to develop staining method and Cajal was intuitive to grasp at once the merit of Golgi staining method. Golgi misinterpreted the overall view of the structural organization of the nervous system, which instead has been worked out

by Cajal. However, they have in common. Both were prolific, strenuous, energetic, and dedicated to their study.



<Figure 2> the nerve network of the cells of Purkinje Sketched by Golgi (Mazzarello, 1996)



<Figure 3> Superficial layers of the human frontal cortex drawn by Cajal on the basis of Golgi impregnation. (Cajal, 1989)

Ⅲ. Literature Analysis and the Result of Teaching Material Development

1. Analysis of The scientific inquiry process of Golgi's research

Based on the literature search, this section will analyze the nervous tissue investigation of Golgi and Cajal respectively with respect to the inquiry process;, and compare the reason why the same procedures reached to the opposite conclusion.

1) The nerve system investigation of Golgi

Golgi invented the staining method, applied it to nervous tissue observation, and concluded that the nervous tissues are a reticular network. He supported the reticular theory with his observation and abduction of nerve impulse studies.

<Table 4> The nerve system investigation of Golgi

Reasoning scheme	Inquiry process	Detailed process
Induction	Observation	Operative observation 1: Golgi attempted to stain the nervous tissue with the traditionally used histological techniques This method was not successful
		Operative observation 2: He tried metal impregnation of nervous tissue, which could stain a limited number of cells, about 1-10% of neurons, in an arbitrary manner.
		Commonness discovery: Nervous tissues were stained in the network manner.
Abduction	Causal Questioning	Generating Causal questions: "Why are the nervous tissues intertwined?"
	Hypothesis generation	Identifying experienced situation: "Previous studies showed the nerve impulse through pipe-like pathway"
		Generating hypothetical explanations: "Nerve system is forming an complicated network and that the nervous impulses stretch along that network"
Deduction	Inventing method and criteria	Inventing test method : The black reaction Golgi discovered was repetitively used.
		Inventing criteria for evaluation : If individual sub-organs of brain look networked, the hypothesis will be supported.
	Evaluating	Collecting result: Brain fragments including cortex, hippocampus, and

	hypothesis	cerebellum were stained and observed by the light microscope.
		Evaluating hypothesis and Stating conclusion : "All samples showed network and the reticular theory explains the structure of the nerve system"

2) The nerve system investigation of Cajal

Cajal followed the Golgi staining and observed individual cells contiguous to one another. He supported the neuron doctrine that nervous system has cell-based structure.

<Table 5> The nerve system investigation of Cajal

Reasoning scheme	Inquiry process	Detailed process
Induction	Observation	Operative observation 1: Cajal employed Golgi staining method to nerve tissue investigation - Network structure was observed.
		Operative observation 2: He mainly used the Golgi staining and Ehrlich's methylene blue stain - This modification enabled a higher resolution of the tissue staining.
		Commonness discovery: Nervous tissues were stained in the network manner.
Abduction	Hypothesis generation	Identifying experienced situation: "Previous studies showed cells of other organs are composed of cells"
		Generating hypothetical explanations: "Nerve system consists of individual cells contiguous to each other".
Deduction	Inventing method and criteria	Inventing test method : The modification of Golgi staining was repetitively used.
		Inventing criteria for evaluation : If individual sub-organs of brain have the cell-based structure, the hypothesis will be supported.
	Evaluating hypothesis	Collecting result: Brain fragments including cerebellum, retina, and the spinal cord were stained and observed by the light microscope.
		Evaluating hypothesis and Stating conclusion : "All samples revealed individual cells and the neuron doctrine explains the structure of the nerve system"

3) Why Golgi and Cajal reached to the opposite conclusion?

They started from the Golgi staining, Cajal modified it. This was the first cause that brought about the different conclusion. Also, the abducted process was different. Golgi was for the nerve impulse and Cajal was for the cell theory. They entertained different point of view, which led them to the quite disparate conclusions.

2. Teaching framework Design based on the analysis

Literature investigation and analysis of scientific inquiry process done by two biologists, following worksheet was developed. This worksheet is expected to offer to the high school students who are learning the neuron structure.

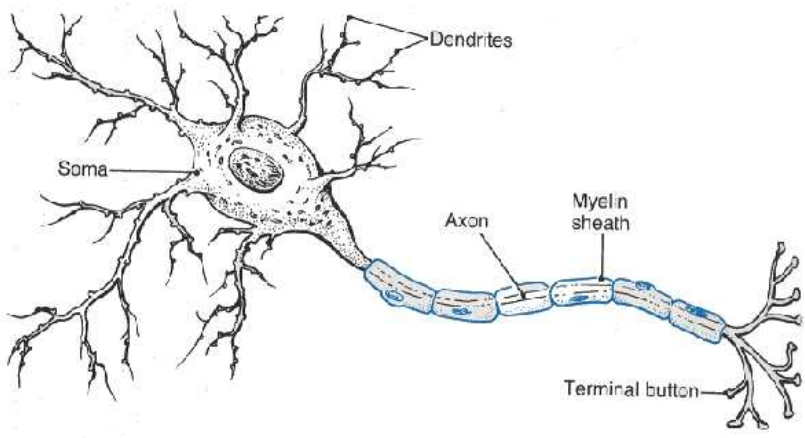
<Table 6> Teaching Worksheet

Purpose

1. Draw students' interest and attention through historical basis of nervous system.
2. Lead students to question why the conclusion of Golgi and Cajal were different and investigate the inquiry process.
3. Relate the content knowledge students learn to the history of nerve system study.

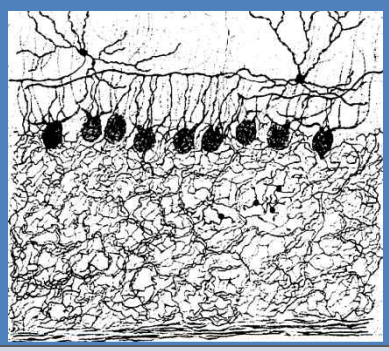
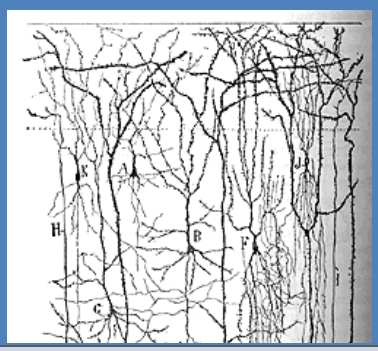
Procedure

1. We will have a closer look at the neuron. When and how do you think the neuron was discovered?



2. To see the neuron, how will you design the investigation process? Think free.

3. Following table shows the inquiry process of Golgi and Cajal.

Inquiry process Drawing of each biologist	Detailed process of Golgi 	Detailed process of Cajal 
Observation	Operative observation 1: Golgi attempted to stain the nervous tissue with the traditionally used histological techniques. This method was not successful	Operative observation 1: Cajal employed Golgi staining method to nerve tissue investigation. Network structure was observed.
	Operative observation 2: He tried metal impregnation of nervous tissue, which could stain a limited number of cells, about 1-10% of neurons, in an arbitrary manner.	Operative observation 2: He mainly used the Golgi staining and Ehrlich's methylene blue stain. This modification enabled a higher resolution of the tissue staining.
	Commonness discovery: Nervous tissues were stained in the network manner.	Commonness discovery: Nervous tissues were stained in the network manner.
Causal Questioning	Generating Causal questions: "Why are the nervous tissues intertwined?"	Generating Causal questions: "Why do the staining result show the individual unit?"
Hypothesis generation	Identifying experienced situation: "The nerve impulse passes through pipe-like pathway."	Identifying experienced situation: "Cells of other organs are composed of cells."
	Generating hypothetical explanations:	Generating hypothetical explanations:

	"Nerve system is forming an complicated network and that the nervous impulses stretch along that network."	"Nerve system consists of individual cells contiguous to each other."
Inventing method and criteria	Inventing test method : The black reaction Golgi discovered was repetitively used.	Inventing test method : The modification of Golgi staining was repetitively used.
	Inventing criteria for evaluation : If individual sub-organs of brain look networked, the hypothesis will be supported.	Inventing criteria for evaluation : If individual sub-organs of brain have the cell-based structure, the hypothesis will be supported.
Evaluating hypothesis	Collecting result: Brain fragments including cortex, hippocampus, and cerebellum were stained and observed by the light microscope.	Collecting result: Brain fragments including cerebellum, retina, and the spinal cord were stained and observed by the light microscope.
	Evaluating hypothesis and Stating conclusion : "All samples showed network and the reticular theory explains the structure of the nerve system"	Evaluating hypothesis and Stating conclusion : "All samples revealed individual cells and the neuron doctrine explains the structure of the nerve system"

1) Which steps were differently developed between them?(Which steps influenced the different conclusion?) Mark to the table and Reason why.

2) Whose study do you think support the neuron structure we are learning?

3) Golgi and Cajal were the co-laureates of the Nobel Prize in physiology or medicine in 1906. Why do you think Golgi won the Nobel Prize with Cajal even though he misinterpreted his data result?

4) Following chronology is the history relevant to neural system study. Fill the blank with the proper subject; Golgi is G, Cajal is C, Golgi and Cajal are G & C.

1791 Luigi Galvani discovered continous and electrical nerve impulse. ( ) applied this discovery to explain his observation.

1838-1839 The cell theory that tissues are composed of cellular elements had been enunciated. ( ) applied this discovery to explain his observation.

1873 ( ) developed silver-staining method.

1887 ( ) faced after 14 years ( )'s staining method after ( ) first

invented it. Cajal
felt admiration toward 'the Savant of Pavia', Golgi. In his autobiography, he recalled the moment as a flash of lightning: "a look was enough".
1809 ( ) showed the axon and dendrite contact (christened as a synapse in 1900)
1906 ( ) shared the Novel Prize in Physiology or Medicine in 1906

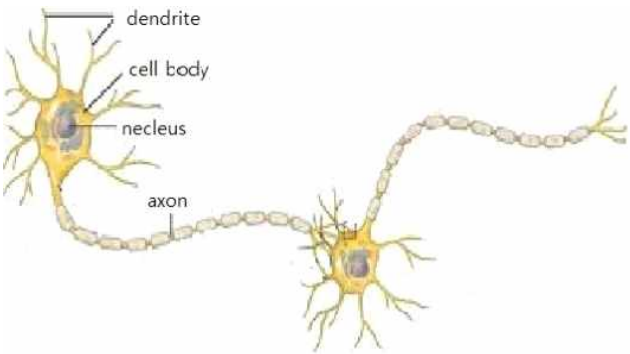
4. Following article introduces the personal character and study contents of Golgi and Cajal.

Golgi was an exceptionally acute and prolific investigator, who provided a number of outstanding observations. Although he misinterpreted the overall view of the organization of the nervous system, he contributed highly to the modern knowledge of its structure. Among other findings, Golgi discovered reticular formation in the spinal cord cells, and he named the structure the Golgi apparatus.

An Indefatigable and Creative Scholar, Cajal's opus provided the foundation of modern neuroanatomy, with a detailed description of nerve cell organization in the central and peripheral nervous system of many different animal species. Cajal defined "the law of dynamic polarization," stating that the nerve cells are polarized, receiving informationon their cell bodies and dendrites,and conducting information to distant locations through axons,

1) Which Characters did the biologists have? What can you learn? Discuss in pairs.

2) According to the BOLD, to which direction does the 'information' flow in the figure below? Draw an arrow. Also, circle where the synapses are located.(synapsemeansthe areaaxoncontacts)



Ⅳ. Conclusion

Biological history can be an interesting teaching resource. Biology has developed the volume of knowledge with biologists and biological inquiry process. If students learn with history, they can thoroughly understand in a contextual manner. This study shows that Golgi and Cajal's research history can be a promising teaching material when students learn the neuron structure and synapse. Students would face the story beyond the content knowledge. There are tens of teaching materials applying the biological history. However, the Golgi and Cajal story seems not having been utilized so far to high school biology. This may be the first practical study employing two Laureates of 1906 Nobel Prize in physiology and medicine.

On the other hand, using this study result must be cautious in two points. First, teachers should not use the history of science as "triumphant discovery" or "fatal error." Introducing some scientists in the past are losers rather than contributors, for example, Golgi and reticular theory, can bear negative outcomes: It may imply that science has a right answer and is static. Second, the most important thing is effectiveness teaching biology contents. The history of biology is a helpful tool, not a burden to memorize. Applying the history of biology to biology teaching with a considerate approach is expected to be useful. Also, future studies are needed to verify the pedagogical effect of the worksheet.

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국문요약

생물학사를 적용한 생물 탐구는 과학자들의 연구 과정을 고찰하고 학생들이 과학자의 탐구 과정을 이해할 수 있는 효과적인 방법이다. 본 연구는 1906년 노벨 생리의학상 공동 수상자인 골지와 카잘의 연구 과정을 되짚어본다. 이 연구의 목적은 먼저 골지와 카잘의 연구 과정을 살펴보고, 이를 바탕으로 뉴런과 관련한 내용을 학습할 때 활용할 수 있는 생물학사 기반 탐구 활동지를 개발하는 것이다. 이를 위해 먼저 과학 탐구 과정에 대해 소개하였다. 이 과정에 각각의 과학자가 수행한 탐구 과정을 대응시키는 과학자의 탐구 과정 분석을 거친 후, 이를 바탕으로 뉴런에 대해 교수 학습할 때 활용 가능한 학생 활동지를 제작하였다. 개발된 학습지는 중고등학생을 대상으로 하였다. 앞으로 이와 같이 생물학사를 적용한 생물 탐구 프로그램이 다양하게 개발될 수 있기를 기대한다.

주요어: 생물학사, 과학 탐구 과정, 골지, 카잘, 교수 학습 방법

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