A Possible Scientific Inquiry Model based on Hypothetico-Deduction Method Involving Abduction

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Abstract: The aims of this study are to investigate two main problems for the hypothetico-deduction method and to develop a scientific inquiry model to resolve these problems. The structure of this scientific inquiry model consists of accounts of the context of discovery and justification that the hypothetico-deduction holds as two main problems : 1) the heuristic flaw in the hypothetico-deduction method is that there is no limit to creating hypotheses to explain natural phenomena; 2) Logically, this brings into question affirming the consequent and modus tollens. The features of the model are as follows: first, the generation of hypotheses using an analogical abduction and the selection of hypotheses using consilience and simplicity; second, the expansion phase as resolution for the fallacy of affirming the consequent and the recycle phase as resolution for modus tollens involving auxiliary hypotheses. Finally, we examine the establishment process of Copernicus's Heliocentric Hypothesis and the main role of the history of science for the historical invalidity of this scientific inquiry model based on three examples of If/and/then type of explanation testing suggested by Lawson (*International journal of science and Mathematics Education*, 2005a, 3(1): 1-5) We claim that this hypotheticho-deduction process involving abduction approach produced favorable in scientific literacy rising for science teacher as well as students.

Key words: scientific inquiry model, hypothetico-deduction method, analogical abduction, simplicity, affirming the consequent, *modus tollens*, Copernicus's Heliocentric Hypothesis, *If/and/then* type of explanation testing

1. Introduction

Regardless of numerous scientific methods that can ultimately be verified, the current analysis suggests that many, but not all, scientific discoveries are made essentially by the hypothetico-deduction method. Several studies (Lawson, 1999; Lawson & Worsnop, 1992; Wong, 1993; Park, Kim, Kim & Lee, 2001, Oh, 2007) have found that many secondary school and college students have difficulties in making inferences using the **Hypothetico-Deductive Method (HD method)**. These difficulties extend beyond solving problems and understanding scientific concepts to include understanding the nature of science. Accordingly, some studies stress that students should be taught to make inferences with the hypothetico-deduction method.

However, according to Hanson (1961a, 1961b), these 'hypothetical or hypothetico-deductive procedures' are based on the premise that a new concept that explains a phenomenon or hypothesis is not invented or created. At best, new concepts allow for the elimination of some hypotheses or the development of others. Consequently, logical empiricists and Popperians focused on the epistemology of verification and falsification and thus avoided any method of concept development. In addition to not providing an explanation for the formation of hypotheses, hypothetico-deductivism has **heuristic** and **logical** problems (Kleiner, 1993, pp. 12-13). Heuristic refers to the method of developing a theory or hypothesis from information through observation or experience. That is, a heuristic is interested in problem-solving rules and is related to the context of discovery. The modern concept of methodology considers empirical data that do not need an

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explanation and the hypothetical solutions as given. Methodology refers to finding the rules to evaluate these solutions and is therefore related to the context of justification (Lee, 1995, p. 91). Because exploring the development process of science is an important basis for understanding the nature of science, it is necessary to consider the exploration of the history of science

The activity of science – as it is represented by the growth of knowledge – involves two equally important sets of processes (Duschl, 1990, p.8).

First there are the processes associated with the generation of scientific knowledge claims. Also called the "context of discovery," these processes address the developmental characteristics of scientific knowledge. The context of discovery, then, involves the origin and evolution of ideas. The historical and sociological criteria of many episodes in science contribute significantly to defining the context in which the restructuring of knowledge actually occurs.

The **second** sets of processes are the familiar ones for the justification of the scientific knowledge. These processes in the growth of scientific knowledge associated with the testing of scientific knowledge claims come under the heading of the "context of discovery." Gathering and establishing the validity and reliability of scientific evidence are addressed by the context of justification. It involves the direct application of logical and empirical criteria science uses to legitimize its knowledge claims (Duschl, 1990, p.8).

In other words, science has a set of standards that must be learned, and the history of science has shown these standards change. This two-faced nature of science has dominated science education practice during the twentieth century. Focusing the investigative procedures of science, we obtain the inquiry and process approach to science.

There is a problem, however: The processes of science as portrayed in the majority of elementary and secondary science textbooks have focused almost exclusively on activities associated with the context of testing. What results, then, is an incomplete representation of science. What is missing is the chain of reasoning that has brought us to this point of understanding (Duschl, 1990, pp.9-10).

Therefore, the purpose of this study is to develop a scientific inquiry process to understand the nature of science via the history of science. The following research questions were considered:

First, in the hypothetico-deduction method, what are the two problems, and what are their possible alternatives?

Second, what are the characteristics of a possible scientific inquiry model that provide a solution for these problems?

Third, How can be this possible scientific model applied to the establishment of Copernican heliocentric hypothesis in the history of science?

Fourth, what are the implications of the hypothecthico-deduction method involving abduction for science education?

2. Problems with the Hypothetico-Deduction Method

The following is a summary of the two main problems of the hypothetico-deduction method.

First, the heuristic flaw in the hypothetico-deduction method is that there is no limit to creating hypotheses to explain natural phenomena. Recognizing that heuristic variables can create a congestion of hypotheses, Hanson (1961) claimed that the exclusion of nominal hypotheses in the hypothetico-deduction method is possible. Excluding hypotheses requires their classification into promising and not promising categories after an initial assessment of their explanatory power. Therefore, for the initial selection of hypotheses in our study, we set economic feasibility as an important criterion for identifying a promising hypothesis (Kapitan, 1997, p.486). In addition, analogical abduction was used as a strategy to generate hypotheses (Lawson, 2010).

Second, according to Salmon (2002), textbooks for high school and college science classes typically present the following simple version of the hypothetico-deductive method for testing scientific claims (p. 256):

> To see whether a hypothesis is true, drive some prediction from it. If the prediction is true, then the hypothesis is confirmed. If the prediction is false, then the hypothesis is disconfirmed.

Logically, this brings into question **affirming the consequent** and **modus tollens**. Affirming the consequent, in this case, is deductively fallacy. However, because the scheme is inductively incomplete, auxiliary hypotheses were added, and the following improved scheme was proposed. Hypothetico-deductive reasoning that includes auxiliary hypotheses is shown as follows. Here, H represents the hypothesis to be tested, A1 ⋯ An represents auxiliary hypotheses, and q refers to an observable prediction.

If H and A1 ⋯ An,
then q.
q is true.
____
H and A1 ⋯ An are true

Here, auxiliary hypotheses are premises for the main hypothesis and clarify the role of hypotheses in arguments.

The following summarizes the structure of arguments to confirm hypotheses:

1. The hypothesis is initially plausible (it has some degree of prior probability).
2. If the hypothesis and the auxiliary hypotheses are true, then the observable prediction is true.
3. The observable prediction is true.
4. No alternative hypothesis has as high a prior probability as the hypothesis that is being tested.
5. Therefore, the hypothesis is true.

Arguments of confirmation thus have four premises. The first premise states the plausibility of the hypothesis to be tested. The second and third premises are the same premises found in the simplified version of the hypothetico-deductive form of reasoning. The fourth premise again appeals to prior probabilities to compare the hypothesis being tested with alternative hypotheses. The hypothesis that is best confirmed after the test is the one that started out with the greatest degree of plausibility (prior probability) (Salmon 2002, p. 264).

Lawson (2003) expressed **affirming the consequent** as follows.
If ⋯ P,
and ⋯ planned test,
then ⋯ probably q (assuming that nothing goes wrong with the test).
And ⋯ q.
Therefore ⋯ possibly p (meaning that the hypothesis is supported but not proved, as other hypotheses could lead to the same prediction).

However, the hypothetico-deduction method suggested by Lawson, which is a type of affirming the consequent, can be defended based on the following arguments by Salmon.

A hypothesis (p) is regarded as abductively (Lawson, 2010) rather than inductively proposed (Lawson, 1993). Therefore, a hypothesis is considered to have a high prior probability, either compared with other hypotheses or on its own.

According to Peirce, abduction was seen as spontaneous and creative acts of hypothesis generation. Confusing observations that need to be resolved are regarded as similar or analogous to previously explained observations that are already considered to be declarative knowledge. This abduction process is called abductive inference, analogical transfer, or analogical reasoning (Holyoak, 2005; Lawson & Lawson, 1993).

Planned tests include initial conditions, proper equipment and materials, and the working order of the simple hypothetico-deduction method. Salmon (2002, p. 259) proposed that **theoretical background knowledge** is a precondition for hypotheses and that **proper testing conditions** are a precondition for the tests.

In the case of a statement "probably q," the use of the qualifier 'probably' is a type of hypothesis deduction method that employs the logic of affirming the consequent and is deductively false. However, because auxiliary hypotheses were used (Salmon, 2002) but were not clearly expressed, the logic is inductively insufficient; thus, the qualifier 'probably' was used.

In conclusion, the hypothesis (p) is possibly supported but is not proved, as there is no guarantee that prior probability is higher than alternative hypotheses that can actually be observed through some identical prediction.

> The deduction scheme involving the simple modus tollens that is commonly used in classrooms is as follows:
> If p, then q.
> Not q.
> ---
> Not p.
>
> According to Salmon (2002), adding auxiliary hypotheses to this simple scheme presents an improved general form of the argument for disconfirmation, which appears as follows:
>
> If H and A1 ··· An, then q.
> q is false.
> ---
> Either H is false or A1 ··· An is false.
>
> Consider the following statement:
> If the Ptolemaic system is correct, if the telescope is a reliable instrument of observation, and if Venus lies between the Earth and the Sun, then Venus will not reveal a complete set of phases.
> However, if Venus does show phases, then one of the following is true:
> ---
> the Ptolemaic system is incorrect, the telescope is unreliable, or Venus is not between the Earth and the Sun.

A conclusion drawn from such an argument is a deductive consequence of premises. However, the conclusion is not just a rejection of a hypothesis. The conclusion suggests that either the hypothesis or one of the auxiliary hypotheses is false. In actual scientific practice, simply rejecting or replacing auxiliary hypotheses to protect the tested hypothesis is inappropriate. For this reason, the rejection or addition of auxiliary hypotheses is referred to as *"ad hoc"* reasoning. However, people from Galileo's time rejected the reliability of the telescope rather than the Ptolemaic universe. Therefore, auxiliary hypotheses need to be examined.

According to Lawson (2003), modus tollens is expressed as follows:

> If p, then q,
> But not q.
> ---
> Therefore, not p.

Errors stemming from the inconsistency between a predicted and observed result may be due to an ineffective test rather than to errors in the hypothesis. Consequently, a thoughtful application of *modus tollens* is as follows:

> If p and ··· planned test,
> then q (assuming nothing goes wrong with the test, **the test was perfectly controlled**)
> But not q.
> ---
> Therefore, not –p (**unless something did go wrong with the test**).

Here the *modus tollens* reasoning is deductively valid. However, because any hypothesis must be negated with auxiliary hypotheses, a premise that auxiliary hypotheses are true is necessary (Salmon, 2002, p. 260).

To overcome this problem, Lawson has suggested that the given test was perfectly controlled in the expected result and that there was nothing wrong with the process of the test.

The reason for this apparent contradiction is that even if a test produced a different result from the expected, the test cannot distinguish between the main hypothesis having been wrong and one of the auxiliary hypotheses' preconditions having been met. Accordingly, even when an unexpected result is observed, claiming that something was wrong with the test's preconditions (auxiliary hypotheses) can produce many excuses (*ad hoc*), which can make it difficult to disprove the hypothesis. For example, scientific experiments always yield different results, regardless of the context, even when they are conducted in the same manner. Students frequently have failures that arise from problems in a test's preconditions (auxiliary hypotheses), such as the test condition or test order, rather than from the preconditions of the hypothesis, such as theoretical background knowledge. Therefore, teachers often do not trust students' experiments and repeat the tests to confirm the preconditions.

Despite these fallacies of affirming the consequent and the problems of modus tollens including auxiliary hypotheses, Lawson (2010) proposed a scientific inquiry inference model. Many of the problems were overcome by combining the proposed hypothesis with the induction process. The proposed hypothesis is generated through abduction (Puzzling Observation-Causal Question) and an If-And-Then-Therefore scheme. The induction process consists of a test plan for the hypothesis according to deductive prediction, a comparison of the expected and observed result, and a conclusion. Indeed, a more thoughtful analysis one that leads to the acquisition of human knowledge includes the generation of testable ideas and takes the form If-And-Then-Therefore, which has already been shown to be useful as a hypotetico-deduction pattern (Hempel, 1966; Lawson, 1995).

When evidence is contrary to the initial hypothesis, it cannot lead to an immediate rejection. The failure to achieve the expected result can originate from one of two sources: a flaw in the hypothesis or a flaw in the test. Thus, before a hypothesis is rejected, we must reasonably sure that the test was not flawed.

3. Suggestion of a Possible Scientific Inquiry Model Based on the Hypothetico-Deduction Method involving a abduction

Reinforcement for Problems with Lawson's (1995a, 2000, 2010) Scientific Inquiry Model

Lawson (2000, 2010) suggested that knowledge acquisition involves the following elements as depicted in Figure 1 as follows:

1. **Making an initial observation (Puzzling Observation).**
2. **Raising a casual question (Casual Question).**
3. **Generating an initial possible cause as a hypothesis (Proposed Explanation):** The process of hypothesis generation is seen to involve analogies, analogical transfer, and analogical reasoning. The latter involves borrowing ideas that have been found to "work" in other contexts and using them as possible solutions or hypotheses in the present context (Finke *et al.*, 1992; Hestenes, 1992; Wong, 1993).
4. **Assuming that the hypothesis under consideration is correct (If/And/Then):** A test requires imagining relevant conditions that, in addition to the assumed hypothesis, allow the generation of an expected result (a prediction).
5. **Carrying out the imagined test (Conducted Test):** The imagined test must be carried out so that its expected result (the prediction) can be compared with the observed result of the actual test.

6. Comparing expected and observed results (Therefore, conclusion):

A good match means that the hypothesis is supported but not proven. A poor match means that something is wrong with the hypothesis, the test, or both. In the case of a good match, the hypothesis has not been "proven" correct because one or more unstated, and perhaps unimagined, alternative hypotheses may give rise to the same prediction under the test condition (Salmon, 1995). Similarly, a poor match cannot "disprove" or falsify a hypothesis in any ultimate sense. A poor match cannot be said to falsify with certainty because the failure to achieve a good match may be the fault of the test condition(s) rather than the hypothesis (Salmon, 1995).

7. Recycling the procedure (Recycle): In the present example, the initial conclusion was that a hypothesis test was faulty. However, on repeated attempts and with a closer inspection of the test, the hypothesis was rejected, which allowed for the generation, test, and support of the hypothesis.

Typically the 'hypothetical or hypothetico-deductive procedures' do not generate a new concept or hypothesis to be tested. At best, they are only ways to reject or confirm some of the hypotheses that have been submitted. Hypothetico-deductivism has two types of problems: **heuristic** and **logical** (Kleiner, 1993, pp. 12-13). Our study is focused on strengthening these two problem areas, which can strengthen Lawson's (2010) scientific inquiry model as follows:

First, Lawson does not have a clear selection criterion for which hypothesis is to be selected first among the proposed hypotheses. Therefore, we accepted economic feasibility (e.g., consilience and simplicity) from Salmon's (2002) criteria for prior probability so that the hypotheses available for use are selected first. This process remedied the invention of hypotheses and the unclear selection criterion from the problem of methodology in the hypothetico-deduction method (Oh, 2010).

Second, Lawson claimed that when a hypothesis is not supported, the experimental process must be repeated to verify the test conditions (Lawson, 2000). When two results do

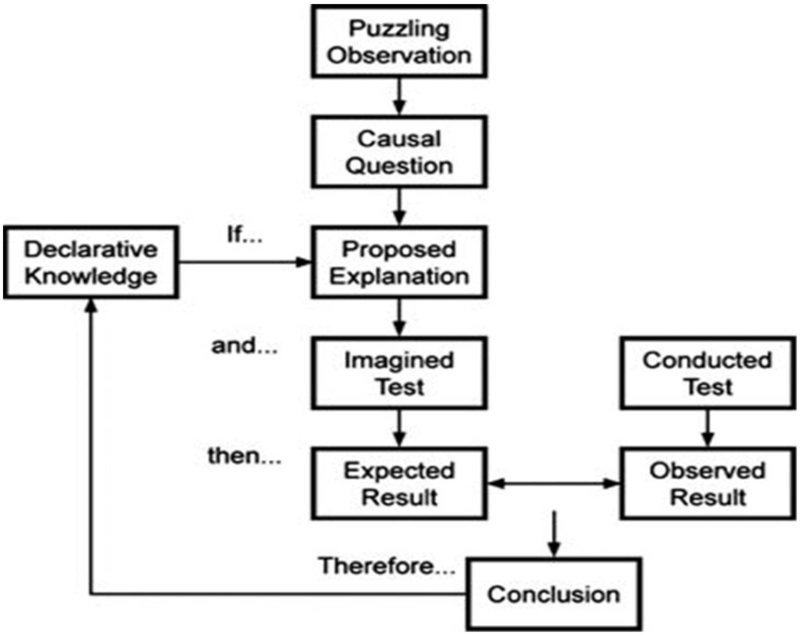

Fig. 1 *Scientific Inquiry Model (see Lawson 2010)*

not match, an error in the hypothesis is not proven, as the hypothesis, the test, or both may have been faulty. Thus, before dismissing the hypothesis, we must verify that the test did not have flaws (Lawson, 2005b). The examination of the theoretical background, as a precondition of the hypothesis which is another type of auxiliary hypothesis is necessary, as well as the examination of test conditions (Salmon, 2002). That is, the test conditions and the other theoretical backgrounds should be examined, and then should be **recycled** until a suitable alternative is suggested and supported.

Third, Lawson (2000) claimed that under the assumption that the hypothesis is correct, the hypothesis is accepted if the expected and observed test results match, but this is simply a provisional acceptance of the hypothesis. Unstated alternative hypotheses can bring about the same prediction under the same test conditions (see Figure 1). Therefore, in this study, this process is called an **expansion**.

In our proposed model, the logical problem in the hypothetico-deduction method a deductive fallacy of affirming the consequent is a transformative process in which the induction is made more powerful with auxiliary hypotheses as test conditions and an expansion process that reinforces additional evidence.

Suggested Scientific Inquiry Model

A open-inquiry activity model based on history of science materials was developed in this study and is represented in Figure 2. We used practical examples to explore how the functional elements of an inquiry activity model and Copernicus's heliocentric hypothesis are applied to a scientific inquiry model.

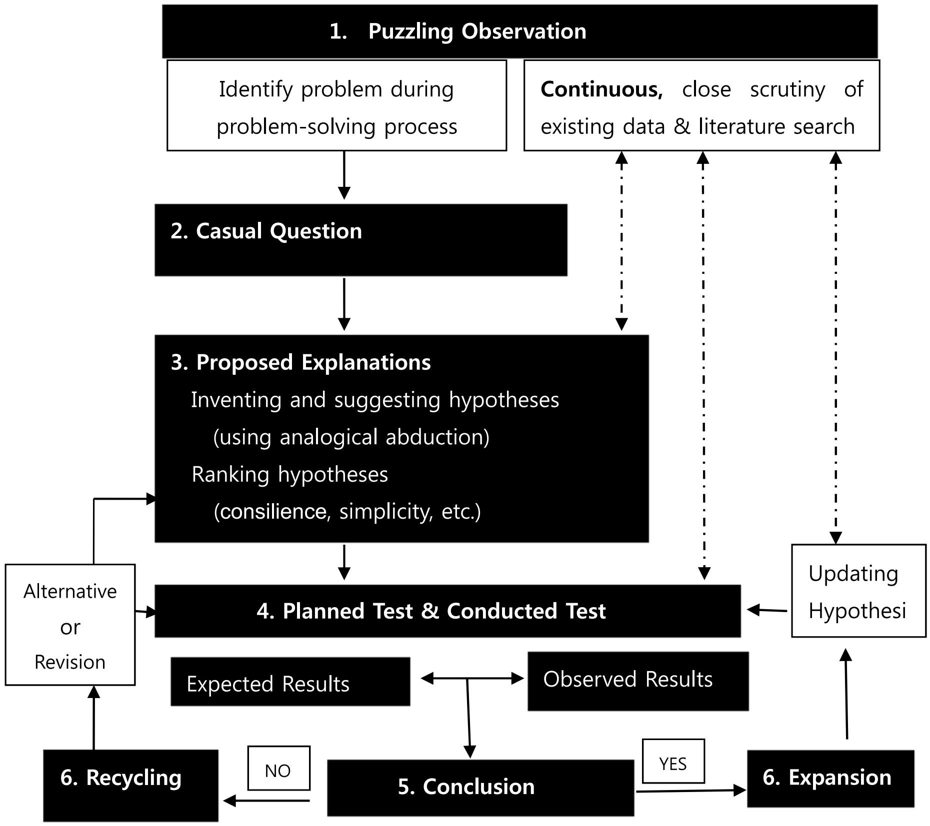

Fig. 2 *A Scientific Inquiry Model based on the hypothetico-deduction method involving a abduction*

4. What is the Center of the World?: Application for the History of Science

Stage 1: Puzzling Observation

Direct data generate a problem with Ptolemy's geocentric hypothesis.

With respect to the planetary position and the precession of the equinoxes, predictions made with Ptolemy's system are never quite confirmed with the best available observations. Further, the reduction of those minor discrepancies constituted the principal problems of astronomical research for many of Ptolemy's successors, just as a similar attempt to connect celestial observation with Newtonian theory generated problems for Newton's eighteenth-century successors.

For some time, astronomers had every reason to suppose that these attempts would be as successful as those that had led to Ptolemy's system. Astronomers were invariably able to eliminate a given discrepancy by making an adjustment in Ptolemy's system of compounded circles. As time went on, a man looking at the net result of many astronomers' research could observe that the complexity was increasing far more rapidly than the accuracy; a discrepancy that was corrected in one place was likely to show up in another (Kuhn, 1996, p. 68).

That recognition was a prerequisite for Copernicus's rejection of the Ptolemaic paradigm and his search for a new one. However, the breakdown of the normal technical puzzle-solving activity was not the only ingredient in Copernicus's astronomical crisis. An extended treatment would also discuss the social pressure for calendar reform a pressure that made the puzzle of precession particularly urgent. In addition, a fuller account would consider the medieval criticism of Aristotle, the rise of Renaissance Neoplatonism, and other significant historical elements. But technical breakdown would remain the core of the crisis (Kuhn, 1996, p. 69).

Stage 2: Casual Question

Identifying a Problem: What is a casual question?

A causal question suggests a possible hypothesis as a solution for a phenomenon that needs to be resolved. The question is necessary for forming casual hypotheses. One must ask, "What caused this phenomenon?" and "Why does this phenomenon occur?"

〈Phenomenon to be resolved〉 A new alternative was required because of social pressure for calendar reform-a pressure that made the puzzle of precession particularly urgent.

〈Casual Question〉 Is not the artificial introduction of epicycle the reason for such a phenomenon? Is not the heat source of lighting the center of everything? (Using analogical abduction.)

Stage 3: Proposed Explanations

Inventing and suggesting hypotheses

(Simple abduction or Using analogical abduction)

Analogical thinking is also quite common in science. Volta and Amper discovered how to represent electricity in terms of the pressures and flows of fluids. They transformed much of what they already knew about fluids to the domain of electricity (Stavy, 1991).

After repeatedly looking through old data and thinking for a long time, Copernicus concluded that placing the Sun in the center of the universe would allow for a simpler depiction of planetary motion. Upon consideration, where else would be a better place for the Sun that illuminates the universe than the universe's center? He was not the first to claim heliocentric theory. In fact, 2000 years before, Aristarchos (B.C. 310-230) had also claimed heliocentric theory, but he had been completely forgotten (Vigoureux, 2003, p. 86). A hypothesis that uses analogical abduction in a heliocentric theory can be described as following an If/And

/Then approach (Hempel, 1966; Lawson, 1995, 2005a).

Based on our prior store of declared knowledge in other domains, we use **Analogical abduction** to invent a hypothesis (a tentative explanation) for a puzzling or surprising phenomenon, based on existing knowledge in other domains (Oh, in press).

(If), the light (p1) illuminating everywhere (p2) makes it bright around, in the dark night (everyday life T1), (and) the Sun (p4) illuminating everywhere to create daytime for all planets including the Earth in universe (expansion T2), is like the Light (p1) in everyday life (T1),

(then), all planets(p3) orbit around the Sun(p4) each at a different speed to show prograde and retrograde motion, and the planets themselves must rotate to create day and night.

(Therefore), there is reason to suspect that Heliocentric theory is true

Continuously, for example,

…., an atomic nucleus is observed by Rutherford.
If …. Planet(p2) orbit the Sun(p1) in Heliocentric theory(T1), and… atomic nucleus(p4) in atomic theory(T2) is like Sun(p1) in the Heliocentric theory(T1), Then,… perhaps electrons(p3) will orbit an atomic nucleus (p4).
Therefore (Hence), there is reason to suspect that Rutherford's atomic theory is true
However, simple abduction produces hypotheses about individual objects, such as the rock musicians. We use **Simple abduction** for example

A young man, Michal, is dressed outrageously is to be explained,
If x is a rock musician, then x can dresses outrageously.
Therefore Michal is a rock musician.

Ranking Hypotheses

Simplicity deals with the conceptual complexity of hypotheses when they have an equal degree of **consilience**. Assessment by simplicity is strongly influenced by 'Ockham's razor,' which is highly relevant to the classification of competing hypotheses (Magnani, 2001, p. 26).

First, if the focus is only on whether there is an accord with the observed planetary positions, it is difficult to find the superior theory among the competing ones. As heliocentric circular orbit cannot be in accord with the observation, Copernicus's theory, like Ptolemy's theory, required the addition of epicycles. The numbers required to suggest the orbit that was in accord with the known observations were almost identical in both systems.

〈Inquiry Planning and Prediction〉 Inquiry experiment design entails identification of variables, maintenance of constant control variables, manipulation of moderator variables, observation, and measurement plans (Salmon, 2002). A research hypothesis is an expected statement related to the research or a potential answer to the research question. In correlation studies,

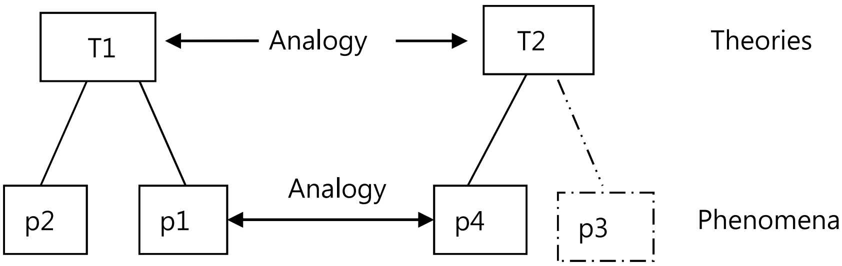

Fig. 3 *The criterion analogy (modified by Thagard, 1988, p.93, Figure 5.2)*

experiments, quasi-experiments, and retrospective studies, all hypotheses are stated as expected relationships between moderator and response variables (Bentley, Ebert, & Ebert, 2000). Scientific experiment design begins with the identification of dependent and independent variables. Dependent variables refer to variables that change as moderator variables change. Generally, independent variables are classified into moderator variables and control variables. Moderator variables are independent variables that systematically modify or control, and control variables refer to variables that remain constant and do not have an impact on the outcome (Pakinson, 1994).

1. **If (hypothesis)**: if a certain hypothesis is correct, **and (planned test: auxiliary hypotheses)**, … under assumption (theoretical background), … something to be held in place (control variable), … something to modify (manipulation variable) is possible,
2. **then (expected result)**, … something to be measured or observed **(dependent variable)** would certainly occur.

〈Performance of Inquiry and Conclusion〉 Compare the result of the inquiry with the expected results, and make a conclusion using the relevant scientific concepts to **explain the observed result.**

1. And, or But **(comparison between expected and observed result)** as the result **(determination of the truth of the hypothesis) was in accord, or discord.**
2. Therefore **(conclusion)**, … the hypothesis is supported or unsupported with all auxiliary hypotheses unless another alternative exists **(draw conclusion)**. … **(generalization** only when supported).

(If) Ptolemy's geocentric theory is correct, (and) we can trust our naked observation, planets reflect sunlight in rectilinear propagation and rotate in an epicycle that is centered on a circular orbit of revolution. However, as inferior planets are always aligned with the center of the Sun and epicycle similar to the Earth and the observation of the position of Venus during such a rotation period is possible, (then) certainly planets' prograde and retrograde motions will be available through macroscopic observation.

(And), as in the expected results, the positions of the planets during the rotation period were found to be in prograde and retrograde. (Therefore), Ptolemy's geocentric theory is supported along with the auxiliary hypotheses particularly the description that they rotate in circles in an epicycle that is centered on a circular orbit of revolution, but inferior planets are always aligned with the center of the Sun, the epicycle, and the Earth.

If (If) Copernicus's heliocentric hypothesis is correct, (and) we can trust our naked observation, planets reflect sunlight in a rectilinear propagation, rotate in a circle on an orbit of revolution and epicycle is added, and the observation of the position of Venus during such an orbital period is possible, certainly (then) planets' prograde and retrograde motions will be available through macroscopic observation.

And (And), as in the expected results, the positions of the planets during the orbital period were found to be in prograde and retrograde. Therefore (Therefore), Copernicus's heliocentric hypothesis supported along with the auxiliary hypotheses particularly the description that they simply rotate in circles on orbits of revolution.

The main attraction of the Copernican hypothesis was in how clearly it explained a number of features of planetary motion, which could be explained by the rival Ptolemaic theory only in an unattractive, artificial way. The features are the retrograde motions of the planets and the fact that, unlike the other planets, Mercury and Venus always remain in the proximity of the Sun. In the Ptolemaic system, retrograde motion was explained by the *ad hoc* maneuver of adding epicycles. In the Copernican system, no such artificial move is necessary. Retrograde motion is a natural consequence of the fact that the Earth and the planets orbit the Sun against the background of fixed stars. Similar remarks apply to the problem of the constant proximity of the Sun, Mercury, and Venus. This is a natural consequence of the Copernican system once it is established that the orbits of Mercury and Venus are inside the orbit of the Earth. In the Ptolemaic system, the orbits of the Sun, Mercury, and Venus have to be artificially linked together to achieve the required result (Chalmers, 1999, p. 96).

While consilience was equal, in agreement with the observation, the method of explanation was simpler than the competing theory. According to 'Ockham's razor,' a good explanation does not require much evidence in support of an argument. To choose one among two equally good explanations, a simpler explanation is better (Newth, 2006, p. 89).

simplicity deals with the problem of the level of conceptual complexity of hypotheses with equal consilience. "the degree of coherence of a hypothesis with what it explains and with its cohypotheses is inversely to the numbers of cohypotheses. For example, H1 is preferred to H2 and H3 because it accomplishes the explanation with no cohypotheses" (Thargard 1992, p.77). The generate network is shown in Figure 4.

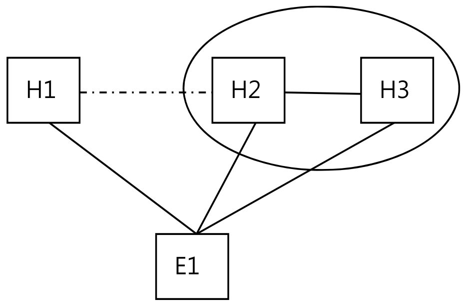

Fig. 4 *Simplicity, H1 defeats H2 because it gives simpler explanation of the evidence (modified by Thagard 1992, p.78, Figure 4.5)*

Stage 4: Planned Test and Conducted Test

Inquiries, Planning, and Expected Results

The phases of Venus offered positive support for the heliocentric system. In the geocentric system, Venus is always more or less between the Sun and the Earth and must always appear as a crescent (see Figure 5 (a)). In the heliocentric system, Venus travels behind the Sun and can appear nearly full—which the telescope reveals (see Figure 5 (a)) (Westfall, 1971, p. 13).

Conducted Test and Observed Results

The telescope reveals Venus, nearly full:

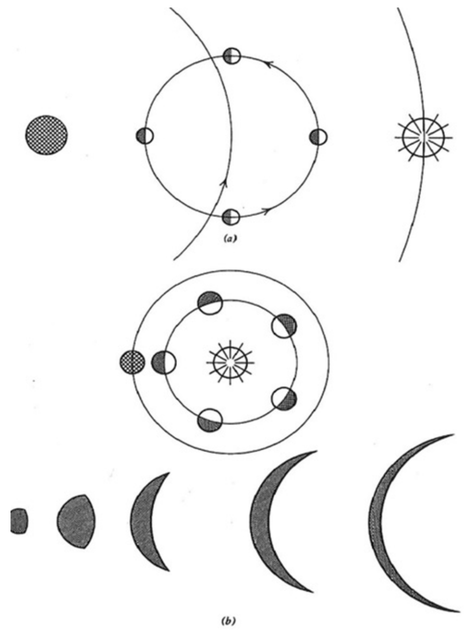

Fig. 5 *Phases of Venus: (a) Ptolemaic system, (b) Copernican system (Westfall, 1971, p. 14).*

Stage 5: Conclusion

Galileo thought that this change of appearance occurred because Venus orbited around the Sun. This change is possible only when Earth and Venus orbit around the Sun. Ultimately, the changing phases of Venus supported Copernicus (Newth, 2006, p. 102).

Stage 6: Expansion and Recycle

There was one other thing that the telescope did not reveal, though as far as the Copernican revolution is concerned, it was the most perplexing telescopic observation. The telescope did not reveal stellar parallax. From the moment when the Copernican system was born, the crucial relevance of stellar parallax had been obvious.

If the Earth travels around the Sun on an immense orbit, the positions of the fixed stars should change as an observer moves from one end of the orbit to another (see Figure 3). Yet, no stellar parallax appeared to the naked eye, and none appeared through the telescope. As we know today, fixed stars are so far removed that telescopes of considerable power, not developed until the 19th century, are required to distinguish the very small angle. Galileo's telescope could not distinguish it, so the nonappearance of stellar parallax balanced, at the very least, the positive evidence offered by the phases of Venus. The case for the Copernican-Keplerian system stood or fell on the argument of geometric harmony and simplicity (Westfall, 1971, p. 13).

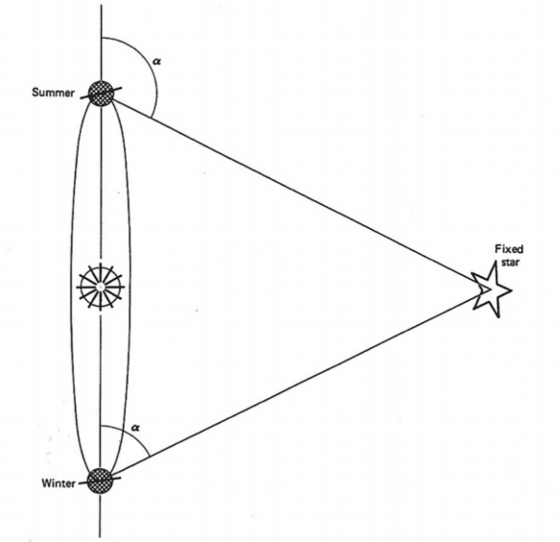

Fig. 6 *Stellar Parallax. The Earth's orbit is shown from the side. For positions of the Earth six months removed from each other, the two angles at which a fixed star is observed should differ from each other if the Earth is traveling around the Sun (Westfall, 1971, p. 15).*

Scientific Inquiry Process for Copernicus's Heliocentric hypothesis

Inquiry Planning and Expected Results

(If) Copernicus's heliocentric hypothesis is correct, (and) (theoretical background) the principles of Galileo's telescope can be trusted, Venus reflects sunlight in rectilinear propagation (initial condition of test), Venus revolves in an orbit that is inside of the Earth's orbit, and observation during orbital period is possible, (then) (expected observation) the phase change of Venus through the telescope will occur in all phases.

Conducted Test and Conclusion

(And) as in the expected results, the phase change of Venus occurred in all phases. (Therefore), Copernicus's heliocentric hypothesis is supported along with the auxiliary hypotheses particularly that Venus exists in an inner orbit from the Earth.

Expansion and Recycling

(And),

(If) Copernicus's heliocentric hypothesis is correct, (theoretical background) a star that has not changed position emits light in a rectilinear propagation to itself, the Earth orbits around the Sun in a one-year cycle, and a high magnification telescope that can precisely observe that star's stellar parallax during the one-year cycle is possible, (then) that star's annual parallax will be discovered. (And), as in the expected results, that star's annual parallax was discovered. (Therefore), another theoretical background and initial condition, as well as Copernicus's heliocentric hypothesis, is more strongly supported than before.

Scientific Inquiry Process for Ptolemy's Geocentric hypothesis

Inquiry Planning and Expected Results

(If) (Main hypothesis) Ptolemy's geocentric hypothesis is correct, (and) (theoretical background: premise of the main hypothesis) the principles of Galileo's telescope can be trusted, Venus reflects sunlight in a rectilinear propagation (initial condition of test), Venus revolves in an orbit at the epicycle between the Sun and the Earth where the centers align, and observation during such a rotation period is possible, (then) (expected observation) the phase change of Venus will not appear in all phases through the telescope.

Conducted Test and Conclusion

(But) unlike in the expected results, the phase change of Venus occurred in all phases. (Therefore), Ptolemy's geocentric theory is not supported in addition to the auxiliary hypotheses.

(And), the theoretical background and the initial condition of the test were correct. (Therefore), Ptolemy's geocentric hypothesis is not supported.

5. Conclusion and Implication

First, what is the hypothetico-deductive method?

The scientific inquiry model was designed to resolve two problems in the hypothetico-deductive method: the problem related to the context of discovery (ambiguity in the method of hypothesis generation and in the criteria for selecting among generated hypotheses) and the problem related to the context of justification (the fallacy of affirming the consequent and the problem of modus tollens for hypotheses, including auxiliary hypotheses).

Second, what is the suggested scientific inquiry model based on the hypothetico-deductive method?

We supplemented heuristic and logical (methodology) problems in the hypothetico-deductive method and proposed a new scientific inquiry model. The characteristics of this inquiry model are that first, an analogical abduction strategy was used for the generation of hypotheses, and the selection of hypotheses involved the principle of consilience and simplicity. Second, the fallacy of affirming the consequent was supplemented in the expansion stage, and the problem of modus tollens for hypotheses, including auxiliary hypotheses, was supplemented in the recycling stage.

Third, what is the understanding of the heliocentric theory according to the scientific inquiry model?

we can better understand the process of Copernicus's hypothesis becoming more strongly supported, from his hypothesis for heliocentric theory, to the changing phase of Venus by Galileo, and finally to the discovery of parallax.

Fourth, what meaning does the suggested scientific inquiry model imply for the history of science?

This research suggests that exploring the development process of science is an important basis for better understanding the nature of science.

Finally, Given that a goal of science education is to enable students to successfully apply concepts in novel situations, the research results imply that instruction should not only be designed to help students acquire the concepts, but also to help them develop skill in utilizing hypothetico-deduction method to evaluate situations in which those concepts may or may not be successfully applied.

Implications for Science Education

The goal of modern science includes understanding the nature of science based Hyoptheticho-deductive Method for Science Education. The development process of scientific theories provides an important basis for better understanding the nature of science. Therefore, the scientific inquiry model proposed in this study implicates for science education in the following ways (Oh, 2011):

First, the **tentativeness** of scientific knowledge is derived from the **creation** of knowledge through empirical observations and inferences.

Second, the expectation of a 'hypothetico-deduction' pattern of inquiry instruction is that students will benefit in terms of improved scientific inference skills. They can also be expected to improve their understanding of the nature of science, especially if such aspects of scientific discovery are explicitly discussed (Ad-El-khalick, 1999).

Third, where new data are considered in light of the reinterpretation of existing data, inferences (the abduction process re-created under a special context) reveal the following: they further refine 'Lakatos's protective belt,' which is said to expand the existing scientific knowledge or form a new nucleus of Lakatos that subsumes the existing core theory (Oh, 2011). That is, comprehensiveness and prescience are the important theory selection criteria.

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References

Ad-El-khalick, F. (1999). The Influence of History of Science Courses on Students' Conceptions of the Nature of Science. Unpublished doctorial dissertation, Corvallis, OR: Oregon State University.

Bentley, M., Ebert, C., & Ebert, E. (2000). The natural investigator: A constructivist approach to teaching elementary and middle school. Belmont, CA: Wadsworth.

Chalmers, A. F. (1982). What is this thing called science? (2nd ed.). Miton Keynes: Open University Press.

Chalmers, A. F. (1999). What is this thing called science? (3rd ed.). Cambridge: Hackett Publishing Company, Inc.

Bybee, R. W., Powell, J. C., & Trowbridge, L. W. (2008). Teaching secondary school science: Strategies for developing scientific literacy (9th ed.). Upper Saddle River, New Jersey: Meririll.

Finke, R. A., Ward, T. B., & Smith, S. M. (1992). Creative cognition: Theory, research and applications. Cambridge, MA: MIT Press.

Hestenes, D. (1992). Modeling games in a Newtonian world, American Journal of Physics, 55, 440-454.

Hanson, N. R. (1961a). Patterns of discovery, Cambridge: Cambridge University Press.

Hanson, N. R. (1961b). Is there a logic of scientific discovery? In Feigl, H. & Maxwell, G. (Eds.), Current Issues in the Philosophy of Science. New York: Holt Reinhart and Winston.

Hempel, C. (1966). Philosophy of natural science. Upper Saddle River, NJ: Prentice-Hall.

Holyoak, K. J. (2005). Analogy. In Holyoak, K.J. & Morrison, R. G. (Eds.), The Cambridge handbook of thinking and reasoning (pp. 117 142). New York: Cambridge University Press.

Kapitan, T. A. (1997). Peirce and the structure of Abductive Inference, In N. Hauser, D.D.Robwetts and J. van Evra (eds.), Studies in the logic of Charles Sanders Peirce (pp. 477-496), Indiana University Press, Bloomington and Indianapolipolis.

Kleiner, S. A. (1993). The logic of discovery: A theory of the rationality of scientific research. Dordrecht: Kluwer Academic Publishers.

Khishfe, R., & Lederman, N. (2006). Teaching nature of science within a controversial topic: Integrated version nonintegrated. Journal of Research in Science Teaching, 43(4), 395-418.

Kuhn, T. S. (1996). The structure of scientific revolutions. Chicago: University of Chicago Press.

Lawson, A. E. (1993). Deductive reasoning, brain maturation, and science concept acquisition: Are they linked? Journal of Research in Science Teaching, 30(9), 1029-1051.

Lawson, A. E. (1995). Science teaching and the development of thinking. Belmont, CA: Wadsworth Publishing Company.

Lawson, A. E. (1999). What should students learn about the nature of science and how should we teach it? Journal of College Science Teaching, 28, 401-411.

Lawson, A. E. (2000). How do humans acquire knowledge? And what does that imply about the nature of knowledge? Science & Education, 9, 577-598.

Lawson, A. E. (2005a). CONDUCTING HIGH QUALITY EDUCATIONAL RESEARCH. International journal of science and mathematics education, 3(1), 1-5

Lawson, A. E. (2005b). What is the role of induction and deduction in reasoning and scientific inquiry?. Journal of Research in Science Teaching, 42(6), 716-740.

Lawson, A. E. (2010). Basic inferences of scientific reasoning, argumentation, and discovery. Science Education, 94, 336-364.

Lawson, D. I., & Lawson, A. E. (1993). Neural principles of memory and a neural theory of analogical insight. Journal of Research in Science Teaching, 30(10), 1327-1348.

Lawson, A. E., & Worsnop, W. (1992). Learning about evolution and rejecting a belief in special creation: effects of reflective reasoning skill, prior knowledge, prior beliefs and religious commitment. Journal of Research in Science Teaching, 29, 143-166.

Lee B. J. (1995). The problems of scientific methodology and rationality. Vol. 1, 89-116.

Magnani, L. (2001). Abduction, reason, and science: Processes of discovery and explanation. New York: Kluwer Academic/Plenum Publishers.

Metzler, M. (2005). Instructional models for physical education. In Smith P.A. (Ed.), Massachusetts: A Person Education Company.

Newth, E. (2006). Jaktwen pa sannheten, Gyldendal Agency (Trans. Min-Yong Lee, (2006), Easy and Interesting History of Science, Eclio (Seoul)).

Noh, T. & Scharmann, L. C. (1997). Instructional influence of a molecular-level pictorial presentation of matter on students, conceptions and problem-solving ability. Journal of Research in Science Teaching, 34(2), 199-217.

Oh, J.-Y. (2012). Understanding Scientific Inference In The Natural Sciences Based On Abductive Inference Strategies. In L. Magnani and P. Li (Eds.), Philosophy and Cognitive Science: Western & Eastern Studies (Sapere 2), (pp. 221-237). New York: Springer-Verlag.

Oh, J.-Y. (2011). USING AN ENHANCED CONFLICT MAP IN THE CLASSROOM (PHOTOELECTRIC EFFECT) BASED ON LAKATOSIAN HEURISTIC PRINCIPLE STRATEGIES. International journal of science and mathematics education, 9(5), 1135-1166.

Oh, J.-Y. (2011). Debate for the Nature of Science and Education (pp.135-140), Proceeding of the 2011 Regular Meeting of the Korean Philosophy of Science Society.

Oh, J.-Y. (2010). Defending problems with Peirce's concept of abduction. Journal of Korean Philosophical Society, 113, 215-255.

Oh, J.-Y. (2007). Proposing enhanced Hypothetico-deductive Program of a scientific inquiry process. Sungkyunkwan University Humanities Research Institute, Humanities Science, 39, 215-242.

Parkinson, J. (1994). The effective teaching of secondary science. London: Longman.

Park, J., Kim, I., Kim, M., & Lee, M. (2001). Analysis of students' processes of confirmation and falsification of their prior ideas about electrostatics. International Journal of Science Education, 23(12), 1219-1236

Salmon, M. H. (1995). Introduction to logic and critical thinking (3rd ed.). Fort Worth, TX: Harcourt Brace.

Salmon, M. H. (2002). Introduction to logic and critical thinking (4th ed.). USA: Thomson Learning, Inc.

Stavy, R. (1991). Using analogy to overcome misconceptions about conservation of matter. Journal of Research in Science Teaching, 28(4), 305-313.

Thagard, P. (1988). Computational philosophy of science, MIT Press.

Thagard, P. (1992). Conceptual Revolutions, Princeton, NJ: Princeton University Press.

Vigoureux, J. M. (2003). Les pommes de Newton. Paris: Albin Michel S.A., (Trans. Hee-Jung Lee, (2005), Newton's Apple, NuRim book(Seoul)).

Westfall, R. S. (1971). The construction of modern science, New York: John Willey & Sons, Inc.

Wong, E. D. (1993). Self-generated analogies as a tool for constructing and evaluating explanations of scientific phenomena. Journal of Research in Science Teaching, 30(4), 367-380.