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A Preliminary Study on High School Students' Understanding of the Distinction between Scientific Theories and Scientific Laws

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과학 이론과 과학 법칙의 차이에 대한 고등학생들의 인식 연구

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Abstract: The purpose of this study is to explore high school students' understanding of the distinction between scientific theories and scientific laws. Understanding of the distinction between these two concepts, which belong to the nature of science, has been receiving little attention. We surveyed thirty-two students from a local high school with three-part, open-ended questionnaire. The result revealed that these students shared common misconceptions such as 'scientific theories are unproven, scientific laws are proven and absolute', and 'if a theory is proven with enough evidence, it becomes a law'. Moreover, students tend to regard earth science less sophisticated than physical science, because they recognize a lot of its theories to be unproven in their view. It is indicated further that teaching the difference between scientific theories and laws explicitly could help students possess more appropriate view toward earth science.

Keywords: scientific theories, scientific laws, nature of science, earth science education

요 약: 본 연구의 목적은 학생들이 과학 이론과 과학 법칙의 차이를 어떻게 이해하고 있는가를 알아보는 것이다. 과학 지식의 서로 다른 종류인 과학 이론과 과학 법칙에 대해서 올바르게 이해하고 있는 것은 과학의 본성을 이해하는 데 있어서 매우 중요함에도 불구하고 이에 대한 연구는 충분히 이루어지지 않고 있기 때문이다. 본 연구에서는 서울 지역의 고등학교 학생 32명을 대상으로 개방형 질문으로 구성된 설문을 실시하였다. 조사 결과, 학생들은 '과학 이론은 아직 증명되지 않은 것이며, 과학 법칙은 확실히 증명된 것이다.' 및 '과학 이론이 충분한 증거가 뒷받침되어 증명되면 법칙이 된다.'는 오개념을 가지고 있는 것으로 나타났다. 아울러 학생들이 알고 있는 과학 이론의 상당수가 지구과학 과목에 포함되고, 알고 있는 과학 법칙의 대부분이 물리, 화학 과목에 포함되어 있는 것으로 미루어, 지구과학을 덜 과학적인 학문으로 잘못 인식하고 있을 가능성도 보였다. 따라서 과학 이론과 과학 법칙에 대한 분명한 차이를 이해하는 것은 지구과학에 대한 올바른 인식에도 도움을 줄 것으로 기대된다.

주요어: 과학 이론, 과학 법칙, 과학의 본성, 지구과학교육

Introduction

Misunderstanding of distinction between scientific theories and scientific laws is one of the reoccurring misconceptions in the nature of science (McComas 2004). General misconceptions which occurred commonly among the public are 'scientific theories are not absolute but scientific laws are absolute' and/or 'if a scientific theory is proven with enough evidences then it becomes a scientific law' (Chiappeta and Koballa, 2004; Lederman *et al.*, 2002; McComas, 1998; McComas, 2004). However, scientific theories and scientific laws are different kinds of scientific knowledge (Chiappeta and Koballa, 2004; Dilworth,

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1994; Lederman *et al.*, 2002; McComas, 1998; McComas, 2004). Scientific laws are descriptive statements of relationship and/or regularities among observed phenomena. Meanwhile, scientific theories are inferred explanation for relationship and/or regularities among observed phenomena (Lederman, *et al.*, 2002). Although scientific theories and scientific laws are related and mutually supportive to each other (Trusted 1979), scientific theories are not unproven laws and do not develop into scientific laws. Both scientific theories and scientific laws are tentative and subject to change (Lederman and Lederman, 2004).

If then, why do students misunderstand scientific theories and scientific laws? Clough and Olson (2004) suggested the four possible sources that might convey mistaken notions about the nature of science to students: the language used by science teachers, the cookbook nature of lab, the textbook, and the common assessment strategies. Among these possible sources, the language used by teachers or in textbooks may act as the primary source to convey mistaken notions about scientific theories and scientific laws. Clough and Olson (2004) clearly pointed that the words 'theory', 'law', 'proven' and 'true' must be used carefully. When these words are used without caution, students can easily develop misconceptions due to the confusion between the scientific meaning and the general meaning of these words in society.

If students develop and possess such misconceptions about scientific theories and scientific laws, would it affect science teaching and learning in the classroom? If it does, what kind of effect would it be? This study was conducted in the efforts to answer these questions. Thus, the purpose of this study is to explore high school students' understanding of the distinction between scientific theories and scientific laws.

Procedure

Sample

The survey was conducted in November 2003, among thirty-two students in local high school in Seoul. These students were 11th grade, all male and belonged to the science-technology stream. In the light of their willingness to join the science-technology stream, these students were expected to have interests in science. The students were taking physics, chemistry, life science, and earth science courses at the time of survey.

Questionnaire

The full questionnaire used in the survey consisted of three questions. According to Benchmarks for Science Literacy (AAAS, 1993), to understand something, students should be able to explain it, relate it to other conceptions, and to apply it to the novel context. Three survey questions were developed based on this definition. The first was an open-ended question asking students to explain what scientific theories are and what scientific laws are. For the second question, students were asked to give some examples of scientific theories and scientific laws. This question intended for students to relate their concept to examples. The last question provided two examples and asked students to identify them as either a scientific theory or a scientific law, and to explain the reason for their choice. This question intended for students to apply their concept to the new contexts.

One example was selected from the history of science. Once it was believed that 'nature abhors a vacuum' because whenever the air was removed from a vertical pipe touching the water surface, people could see the water going up to fill the pipe. This story was given with an illustration, and students were asked to identify it either as an example of scientific theories or an example of scientific laws. The other example was about black holes. A brief description of explanations and arguments about black holes was given, and as in the former example, students were asked to identify it either a scientific theory or a scientific law and explain their reasoning.

The distinction between scientific theories and scientific laws is closely related to the distinction between observation and inference (Lederman *et al.*, 2002). The vacuum example was selected because it was presenting the result of observation and then, people's inference to explain why it happens. We hoped that students would notice the distinction and identify it as an example of theories. But we also assumed that students may only see the observational part and identify it as an example of law or they may identify it as a theory only because they knew it is not true. Meanwhile, black hole example was selected because it is apparently different from the vacuum example but is also an example of theories.

Data Analysis

The most frequently appeared misunderstandings about scientific theories and scientific laws are 'scientific laws are proven to be true, while scientific theories are unproven yet' and 'when a scientific theory is proven with enough evidences, it becomes a scientific law' (Chiappeta and Koballa, 2004; Lederman *et al.*, 2002; McComas, 1998; McComas, 2004). Thus we compared each response of the first question to these two common misunderstandings. If student's response agrees neither, we re-analyzed it, however only one student agreed neither and all other students agreed either of above misunderstandings or both.

For the responses to the second question, we collected all the examples given by the students and counted how many times each example was mentioned. Most students gave one or two examples, but some suggested more. Also, we examined each example as to which discipline of science it belongs. Since it could be controversial to ascribe a certain example to a specific discipline, instead we examined which high school subject would include each example. We searched the national high school science curriculum and textbooks to find if each of students' examples was appeared there. We also examined how many theories and laws were appeared in the national high school curriculum. Some examples were beyond the high school curriculum, so we extended the analysis to related subjects in colleges. Several examples were appeared in more than one subject.

We examined responses to the third question and counted how many students identified the given example as a scientific theory or as a scientific law. Students' explanations were compared to the result of the first question to know if they apply their concept to the given circumstance.

For inter-rater reliability, two authors examined all responses independently then compared the results. Agreement on responses was initially about 96%. Any difference was re-examined and discussed before the final decision was made.

Results

Students appeared to think that the most important difference between scientific theories and scientific laws is whether they are proven or unproven. Fifteen students answered in this way. Another frequently mentioned idea was that if a scientific theory proves with enough evidences, it becomes a scientific law. Seven students responded in this way, and these students also answered that scientific laws are proven and scientific theories are not proven (Table 1). These answers indicated that they also thought that proven knowledge such as a scientific law is absolutely true. Thus their responses reflected the general misconception that scientific theories are in trial status and they develop to become laws supported by absolute proof (Lederman *et al.*, 2002; McComas, 1998).

Table 2 shows the examples of scientific theories and scientific laws given by students. Twenty-four of 32 students gave examples. Table 2 also shows to which school subject among physics, chemistry, life science, and earth science includes students' examples.

Table 1. Students' responses about the difference between scientific theories and scientific laws

Contents of Responses	No. of Responses
Scientific laws are proven to be true, while scientific theories are unproven yet'	15
When a scientific theory is proven with enough evidences, it becomes a scientific law'.	7
Both	7
Others	3
No Response	7
Total	32

Table 2. Students' examples of scientific theories and scientific laws

Scientific theories			Scientific laws		
Examples	Subject	n	Examples	Subject	n
Relativity*	Ph	16	Newton's law	Ph	10
Evolution	LS, ES	12	Law of conservation of mass	Ph, C	8
Plate tectonics	ES	10	Avogadro's hypothesis	C	8
Drifting Continents	ES	4	Newton's law of universal gravitation	Ph	8
Big Bang	ES	3	Joules's law	Ph	5
Chaos*	Ph	3	Boyle's/Charles's law	Ph, C	5
Origin of the Moon	ES	1	Law of constant composition	C	3
Quantum theory	Ph	1	Law of conservation of Energy	Ph	2
Super strings*	ES, Ph	1	Law of combining volume	C	2
A ball has gravitational potential energy in Earth.	Ph	1	Law of Thermodynamics	Ph	1
Black hole	ES	1	E=mgh	Ph	1
White hole*	ES	1	Coulomb's law	Ph	1
QED*	Ph	1	Law of Gaseous reaction	C	1
			Law of conservation of momentum	Ph	1
			Kepler's law	Ph, ES	1
			Mendel's law	LS	1
			Fleming's left hand rule	Ph	1
			Graham's law	C	1

Ph: physics, C: chemistry, LS: life science, ES: earth science
'n' represents number of responses; students were allowed to give multiple examples.
'*' represents a topic beyond the high school curriculum.

Table 3. Students' classification of examples as theory or laws (n=32)

Example	Scientific Theory	Scientific Law	can't decide
Vacuum	16	8	8
Black hole	24	1	7

The most frequently mentioned examples of scientific theories were 'relativity', 'plate tectonics', and 'evolution'. For the example of scientific law, 'Newton's law' was most frequently mentioned. Eight of thirteen examples of scientific theories were from earth science. Five of thirteen examples, relativity, quantum theory, QED (Quantum Electrodynamics), gravitational potential energy and chaos theory, belonged to physics. Meanwhile, all but one example of scientific laws belonged to physical science. The only exception was Mendel's law from life science.

Table 3 shows the answers to the third question. Students decided whether each of two given examples is a scientific theory or a scientific law. For the vacuum example from the history of science, 16 of 32 students answered that it is a scientific theory, while eight of 32 answered that it is a scientific law. Eight students could not decide. For the black hole example from modern astronomy, 24 of 32 students answered that it is a scientific theory. Again, seven of them could not decide.

Table 4 and Table 5 show students' explanations for their decision. Students seemed to be surer about the black hole example than the vacuum example, however their reasoning was poor. They decided mainly based on whether it is proven or not. These explanations matched students' responses in the first question (Table 1).

Discussion

Students appeared to think that the difference between scientific laws and scientific theories lies with 'being proven or not'. This notion implied that they possessed general misunderstandings about theories and laws in science. As McComas (1998) observed, scientific theories are often regarded as less secure than scientific laws in such misunderstandings. On the other hand, scientific laws are often regarded as

Table 4. Explanations of students' decision about the vacuum example

Identification	Explanation	n
Scientific Theory (n=16)	It is not proven.	7
	There is no mathematical formula representing this relationship	1
	No explanation	8
Scientific Law (n=8)	It is proven.	6
	No explanation	2

Table 5. Explanations of students' decision about the black hole example

Identification	Explanation	n
Scientific Theory (n=24)	It is not proved	16
	There is no mathematical formula	1
	No explanation	7
Scientific Law (n=1)	It really does exist.	1

absolute because 'proof in science' is mistakenly considered to be equal to 'proof in mathematics' (McComas 1998). This indicated that students were failing to understand the tentativeness of scientific knowledge, because they thought a certain type of scientific knowledge, per se the scientific law is absolutely true, although all kinds of scientific knowledge are tentative.

Some students had additional common misconception about the nature of science. They thought scientific theories and scientific laws are in developmental sequence, thus theories become laws once they are accepted with enough evidence. Scientific theories and scientific laws are very different kinds of knowledge (Lederman *et al.*, 2002; McComas, 1998), but these students, like many others who have misconception, saw them as different states of the same kind of knowledge.

There was one student who gave neither answers mentioned above. This student saw scientific theories as explanations of the phenomenon and scientific laws as mathematical expressions of the phenomenon. This student appeared to vaguely understand the difference between theories and laws. Scientific laws are often described in mathematical form. But this student failed to understand that the mathematical forms are used to describe relationships or patterns in nature. Instead, he saw the mathematical forms as a premise to be scientific laws. His explanations of the given examples, vacuum and black holes, showed it. In there, this student answered that neither example was a law because there was no mathematical form to describe them (Table 4 and Table 5).

Table 6. The number of scientific theories and laws appearing in the national high school curriculum of Korea

	Physics	Chemistry	Life science	Earth science
Scientific theories	6	2	0	10
Scientific laws	18	7	1	6

Thus, all but one student had the common misconception about scientific laws and scientific theories. Even that one exception had inadequate understanding about scientific laws. All of them were misunderstanding and misusing the words 'proven' and 'true'. This indicated that the words used in school science should be defined and used carefully.

In addition to students' general idea about scientific theories and laws, what they suggested for typical examples of theories and laws was also interesting. From students' examples of scientific theories and laws, we noticed the following tendencies. First, students chose a lot of examples of scientific theories from earth science, while they chose examples of scientific laws mostly from physical science. Second, most of students' examples of scientific theories are something which cannot be obtained by experiments in laboratories and/or direct observations.

Why students made such choices could be answered in several ways. The most plausible answer is that this result reflected what students had learned in school science. We examined the national high school curriculum for how many scientific theories and laws are mentioned in it (Table 6). We focused only on terminology therefore there is a certain limitation of data. Nevertheless, table 6 shows something about what is taught in school science. In physics, eighteen scientific laws were introduced and there were only six theories. In chemistry, seven laws and two theories were introduced. In contrast, ten theories and six laws were introduced in earth science. Students were learning about scientific laws mainly from physical science and learning scientific theories mainly from earth science. According to this, it seems natural that they made choices shown in table 2. Nevertheless, if students think that physics is more scientific and earth science is less scientific because they see scientific laws mainly in physics and scientific theories mainly in earth science, teachers should be aware of it. For students could obtain wrong impression toward each discipline due to the inadequate understanding of the nature of science.

Another possible answer could relate with scientific methods. Students often mentioned 'being proven by experiments or observations'. They seemed to have misconception that experiments and direct observation usually used in physical science are principal methods in science. Misconception about 'the scientific method' is still there in school labs where stereotypical observation, controlling variables, and controlled experiments are usually taught as 'the scientific method'. Thus, students came to think of different approaches in science as something inferior (Gould 1986). As Mayer (1995) pointed, descriptive and/or historical methods are frequently used in earth science. This difference of investigation methods may have given to students a wrong impression that only scientific knowledge in physical science is properly proved to be laws, while scientific knowledge in earth science is largely uncertain because it cannot be proved by experiments.

The result of this study indicates that misunderstanding about the nature of science could give negative influence to earth science teaching. If students misunderstand the difference between scientific theories and scientific laws, and think that earth science is full of uncertain, unproven theories, they may think that earth science is less scientific. Though seldom mentioned in publications, there has been an old misunderstanding among high school students, that earth science can be studied simply by memorizing facts. In here, students have been unconsciously regarding them as less scientific. At least, the result of this study provided a clue to how this misunderstanding was conceived. It might have started from misunderstanding the nature of science.

Conclusion

We have found out that students misunderstood about the distinction between scientific theories and scientific laws. They failed to understand that scientific theories and laws are different kinds of scientific knowledge. They also thought that scientific theories are in trial state, so theories developed to be laws when enough evidences are provided. This misunderstanding implied that students also failed to understand tentativeness in scientific knowledge, because they thought that scientific laws are proven to be true and do not change.

Moreover, it suggested that this misunderstanding could influence earth science teaching in negative way. Students recalled many theories which are not proved in their view in earth science, while recalled many laws which are proved to be true in their view in physical science. Thus they could have impression that earth science is full of unproven theories compare to physical science. There is possibility that the misunderstanding of the nature of science, especially, misunderstanding about scientific laws and scientific theories precedes misunderstanding of the nature of earth science. This notion requires further studies with more data and critical analysis, thus more explorations about the relationship between the understanding of the nature of scientific knowledge such as theories and laws, and the understanding of the nature of earth science. At least, the result of this study indicated that it is important to correct this type of misunderstanding for the future earth science education. In earth science class, students need to be explicitly taught the difference between scientific theories and scientific laws. It will help students understand that earth science is a discipline with many theories explaining phenomena in nature with creative and logical ideas.

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