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Examining Students' Views on the Nature of Science: Results from Korean 6th, 8th, and 10th Graders

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Abstract

In this study, students' views on the nature of science (NOS) were investigated with the use of a large-scale survey. An empirically derived multiple-choice format questionnaire was administered to 1,702 Korean 6th, 8th, and 10th graders. The questionnaire consisted of five items that respectively examined students' views on five constructs concerning the NOS: purpose of science, definition of scientific theory, nature of models, tentativeness of scientific theory, and origin of scientific theory. Students were also asked to respond to an accompanying open-ended section for each item in order to collect information about the rationale(s) for their choices. The results indicated that the majority of Korean students possessed an absolutist/empiricist perspective about the NOS. It was also found that, on the whole, there were no clear differences in the distributions of 6th, 8th, and 10th graders' views on the NOS. In some questions, distinct differences between Korean students and those of Western countries were found. Educational implications are discussed.

Introduction

The development of students' understanding concerning the nature of science (NOS) has been considered an important and vital part of science instruction. Recently, more specific attention has been paid to developing an adequate understanding of the NOS in response to a call for reform in science education in many countries (e.g., the National Science Education Standards of the USA and the British National Curriculum of the United Kingdom). The national science curriculum of Korea, in which this study is set, also emphasizes a sophisticated understanding of the NOS as an important goal. The results of previous studies concerned with improving students' understanding of the NOS, however, have been very depressing. Researchers reported that students from various age groups, and even teachers, possess both inaccurate and inappropriate views of the NOS regardless of the instruments/methods used in the investigations (see Lederman, 1992, for a review). Although the importance of an adequate understanding of the NOS has been persistently advocated, why do students still have such a limited view? Meichtry (1992), who assumed that the BSCS (Biological Sciences Curriculum Study)—a middle school science program emphasizing the processes of science—could encourage a more sophisticated understanding of the NOS, found no positive effect of the program. Meichtry concluded that, though students' views on the NOS were well assimilated into their mental structures and resistant to change, learning experiences provided in the program did not take into account students' existing knowledge about the NOS, and thus failed to provide students with opportunities to develop new knowledge by fitting it into, revising, or replacing their existing frameworks of knowledge.

Some researchers suggested that the NOS might be best taught to students early in their academic careers. Newton and Newton (1992) and Lederman and O'Malley (1990), for example, suggested that it may be more productive to address the problem earlier and at its roots than to remedy older students' inadequate images about science. Elementary school is a time during which students begin to be exposed to formal science instruction and acquire an understanding of the world around them (Bruer, 1993). Thus, elementary school students may develop their own views on the nature of science and scientific knowledge.

Evidence from the literature on students' general epistemological development gives us more specific insights into whether elementary school students possess their own views on the NOS. Generally, epistemology can be considered as a tool for reflecting on the contents and the instruments of knowledge (Larochelle & Désautels, 1991). Thus, the epistemology of science is directly related to the nature of science and scientific knowledge. Some theorists (e.g., Chandler, 1987; King & Kitchener, 1994), based on the Piagetian developmental framework that assumes the existence of biological, general constraints on students' abstract thinking, argued that an elementary-aged student should be merely an absolutist and/or a naive realist without a particular epistemology because of his/her concrete operational thought and reasoning. According to these theorists, therefore, it is highly unlikely for elementary school students to adequately understand the NOS. However, other theorists (e.g., Montgomery, 1992; Wellman, 1990) advocated the idea that a developing epistemology likely exists at a younger age, and it is possible that a significant growth in epistemological thought can occur during the elementary school years. For example, Montgomery (1992), from a review of the studies on the development of epistemic thought, surmised that even preschool children's thinking about knowledge appears to be more than simply an unconnected set of facts. That is, even preschool children do recognize the existence of the mental world and comprehend that ideas arise from mental activity (Flavell, Green, & Flavell, 1990).

Furthermore, the results of many nontraditional science curricular approaches designed for elementary school students (e.g., Herrenkohl & Guerra, 1998; Metz, 2000; Smith et al., 2000; Solomon et al., 1992) support the existence of an epistemology for elementary-aged students. These approaches have commonly encouraged inquiry-based instructional contexts with authentic scientific activities. These researchers reported that elementary school students successfully engaged in meaningful inquiry and discussions about the inquiry. Elementary school students were also able to understand, though not perfectly, the explanatory nature of scientific knowledge.

Finally, many other science education studies, which investigated young children's images of scientists using the Draw-A-Scientist Test (DAST), also argue for the existence of an epistemology among elementary-aged students. These DAST studies indicated that the stereotypical images of scientists seemed to begin to form, at least, in grade 2 or 3 and remain stable for many years (Newton & Newton, 1992, 1998; Schibeci & Sorenson, 1983; Song & Kim, 1999). To sum up previous relevant research, it might be reasonable to assume that elementary school students do possess their own epistemologies and views on the NOS.

Purposes of This Study

From a perspective of conceptual change learning, students' existing conceptions are very resistant to change and tend to influence learning new concepts. It is certainly difficult to conceive of any approach to teaching without taking into account students' existing conceptions. Thus, it is very important to present students with experiences that have meaningful links with their existing conceptions as well as the concepts about which they are learning. This framework could also be applied to the development of an understanding about the NOS. There is increasing recognition in the science education community that students frequently come to science class not only with naive theories about the particular subject matter they are studying but also with naive epistemologies (Grosslight et al., 1991). In order to successfully teach about the NOS, we must have an understanding of where our students start. That is, there exist needs to examine students' epistemological views, to diagnose their understanding, and to reveal their alternative frameworks about the NOS before implementing any new curriculum/instruction intended to develop students' understanding of the NOS.

Relatively little attention, however, has been paid to elementary-aged students' perspectives about the NOS. The majority of studies investigating students' views on the NOS have focused on middle school (e.g., Carey et al., 1989; Songer & Linn, 1991), high school (e.g., Griffiths & Barman, 1995; Moss, Abrams, & Robb, 2001; Ryan & Aikenhead, 1992), and college levels (e.g., Dagher & BouJaoude, 1997; Ryder & Leach, 1999; Schoneweg-Bradford, Rubba, & Harkness, 1995). Only a few researchers have tried to examine younger students' understanding of the NOS (e.g., Elder, 2002; Smith et al., 2000).

Although there have not been many studies concerning elementary school students' views on the NOS, a few of them successfully explored elementary-aged students' scientific epistemologies using qualitative methods such as an interview (e.g., Smith et al., 2000). The interview method not only enables researchers to overcome the limitations of traditional instruments (i.e., the problem of Likert-type or multiple-choice format item; a more detailed explanation concerning this problem will be provided in the "methods" section) but also permits a more comprehensive understanding of students' views (e.g., the reasons and sources informing the beliefs students hold, the way in which students' views affect their learning, etc.). In many cases, however, researchers and teachers need not only intensive data but also more general and extensive ones on how their students think about science and scientific knowledge. Therefore, in this study, we sought first to explore and characterize 6th-grade students' views on the NOS through the use of a large-scale survey. The results of this study should be informative to science teachers and educators with respect to providing baseline data for future designs of instruction and curriculum.

Another purpose of this study was to compare students' views on the NOS across grade levels and to examine the relationship between students' views on the NOS and their school science experiences. Previous studies have suggested that the mass media might be a possible source of students' images regarding science (Robottom, 1992). Aikenhead (1988), for example, documented that most of the perceptions held by high school students concerning the relationships among science-technology-society (STS) might come from mass media. Song and Kim (1999) also reported students' responses indicating that films, animated movies, science magazines and books, and cartoons were the main sources of their images of scientists. By the time they leave school, however, students have been exposed to a substantial amount of science instruction. Due to this instruction, other researchers suspect that students' beliefs about the NOS may stem from their own school experiences of learning science and carrying out investigations (e.g., Solomon, Scott, & Duveen, 1996; Songer & Linn, 1991). Therefore, through a cross-age comparison, we wanted to gain some insight into whether students' views on the NOS are influenced by their school science experiences. The results of this study may enrich our understanding of the extent to which students are developing their NOS views on the basis of school science and provide implications to consider in designing science curricula at the secondary school level.

The final focus of this study was to characterize potential notable similarities and differences between the respective views on NOS possessed by Korean students and students of Western countries. Although Western science has become the prototype for what counts as science today, the tendency to define science strictly from the viewpoint of Western culture could lead to serious and detrimental ramifications for students from non-Western cultures and languages (Kawagley, Norris-Tull, & Norris-Tull, 1998; Lee, 1997). As Aikenhead (1996) pointed out, if a teacher is more aware of the differences between science culture and their own culture, he/she is enabled to act as a "cultural broker" to help students learn science in the classroom. Griffiths and Barman (1995) reported that they had found differences even among the NOS views of American, Australian, and Canadian students. Thus, it could be predicted that there exist more fundamental differences between the NOS views of Western and non-Western students. Although there has been an abundance of research on students' NOS views, however, only few studies have investigated the NOS views of students from non-Western countries (e.g., Allen & Crawley, 1998; Sutherland & Reg-Dennick, 2002; Waldrip & Taylor, 1999). Furthermore, most of them have been conducted with African or native North American students, and few investigations regarding Asian students' views on the NOS have been reported in the literature. Therefore, we sought to make a cross-cultural comparison between the results of this study and those of previous studies conducted in Western countries. Considering that an increasing number of teachers in Western countries will face multicultural (undoubtedly including Asian culture) classrooms within the next decade (Aikenhead & Otsuji, 2000), the results of this study would provide teachers, both teachers from Western and non-Western countries, with valuable information concerning the influences of culture(s) on respective students' views on the NOS.

Conceptualizing the Nature of Science

Diverse definitions of the NOS have been delineated over several decades. Researchers, as a consequence of this diversity, do not share a common conceptualization of the NOS. In fact, Suchting (1995) argued that, as science grows and our understanding of the universe increases, our views on the NOS are themselves likely to evolve. Scharmann and Smith (2001) further suggested that it is probably impossible to attempt to achieve unanimity on a list of characteristics of the NOS. Nonetheless, there exist several constructs common in the literature concerning the NOS. Values and assumptions inherent to science, scientific knowledge, and the development of scientific knowledge are the most commonly referenced characteristics (Lederman, 1992). Lederman, Wade, and Bell (1998) suggested that these values and assumptions include independence of thought, creativity, tentativeness, empirically based, subjectivity, testability, and cultural and social embeddedness.

As science teachers/educators, we strive to teach the best possible understanding of the NOS. Thus, there exists the possibility for science teachers/educators to provide much greater depth than is necessary or even to provide expositions and abstractions that students are incapable of comprehending in the name of thorough understanding (Smith & Scharmann, 1999). Learning science in school, however, cannot reflect all the activities of scientists (Millar, 1989). Providing novice learners—especially elementary and middle school students—with a philosophically accurate but excessively complex portrayal of the NOS is not reasonable. Previous studies investigating young students' views on the NOS unanimously agree on this point. Elder (2000), for example, proposed five constructs that had been central in the efforts to investigate elementary school students' beliefs about the NOS: the purpose of science, changeability of science, role of experiments in developing scientific theories, coherence of science, and source of scientific knowledge. In their study investigating 8th graders' understanding of the NOS, Solomon et al. (1996) also focused on limited questions (i.e., scientific theories and experiments), because other questions, like the NOS in its social and political settings, were not only too socially demanding for young students to possess thought about, but also had very little connection with the students' school work in science.

We decided to exclude the constructs concerned with the social aspects of science (i.e., STS relationships and social construction of scientific knowledge) from our list of the NOS constructs because it might be very difficult for younger students to have such experiences in their science classes. Based on the review of relevant previous studies (e.g., Elder, 2000; Smith et al., 2000; Solomon et al., 1996), we selected five constructs appropriate for investigating elementary school students' views on the NOS: purpose of science, definition of scientific theory, nature of models, tentativeness of scientific theory, and origin of scientific theory. Wherever possible, we selected constructs for which there was an agreement on an adequate delineation among a majority of philosophers and/or science educators and on which there were empirical data to attempt to investigate students' views.

Methods

Participants

In order to examine elementary school students' views on the NOS, a survey questionnaire was administered to 534 sixth graders (aged 11–12) in Seoul, a metropolitan city in Korea. Seoul has 11 school districts, and all 6th-grade participants were randomly drawn from five elementary schools, which are respectively located in five different school districts in Seoul. We chose 6th graders as representatives of elementary school students for two reasons. First, students younger than 4th grade are known as being insufficiently experienced linguistically to provide meaningful written responses (Stein & McRobbie, 1997). Second, the particle model of matter, which was included in an item of the questionnaire we administered, is taught at the 6th grade in the national science curriculum of Korea.

The questionnaire was also administered to 551 eighth graders (aged 13–14) and 617 tenth graders (aged 15–16) to investigate the effects of school science on students' views about the NOS. From each school district, in which the elementary schools participating in this study are located, we selected respective pairs of a middle school and a high school. Thus, students from each set of schools possessed similar socioeconomic backgrounds. Table 1 shows the numbers of students by grade and gender. Korea has a school system of 6-3-3-4 (i.e., six years for elementary school, three years for middle school, three years for high school, and four years for college), and students enter elementary school at six or seven years of age. Therefore, those two groups correspond to middle (8th-grade) and high (10th-grade) schools, respectively. At the beginning of 11th grade, Korean high school students have to choose either a science track or a non-science track for the rest of their schooling. The science/non-science track student ratio, however, varies from school to school. Therefore, we chose 10th-grade students as the representative of high school students in order to avoid the problems that might occur when 11th- or 12th-grade students are sampled (i.e., the science/non-science track student ratios of participants is not in accord with the overall ratio). Eighth graders were selected as the representative of middle school students because they lie in the middle of 6th and 10th graders.

Table 1. Sample of Students

Grade	6th Graders	8th Graders	10th Graders
Male	278	289	320
Female	256	262	297
Total	534	551	617

Although the sample for this study was selected only from five school districts in one metropolitan city, we did not perceive it to be a likely threat to the representativeness of the selected sample. This assumption was based on the fact that most schools in Korea, except for some special schools, follow the national curriculum, which results in homogeneous learning and teaching in terms of quantity as well as quality. The report of the Ministry of Education in Korea (Ministry of Education, 2000), which indicated that schools in Korea are generally quite homogeneous in terms of their academic standards, is also consistent with this assumption.

Development of the Instrument

Since the early 1960s, a number of instruments specially designed to assess students' views on the NOS have been developed, e.g., the Test on Understanding Science (Cooley & Klopfer, 1961), the Nature of Science Scale (Kimball, 1968), and the Nature of Scientific Knowledge Scale (Rubba, 1976). Most instruments, with few exceptions, were a Likert-type or multiple-choice format, which reflected the overwhelming emphasis on a quantitative approach to assessment in that era. These types of instruments have the advantage of being easily scored and permitting researchers to quantify students' understanding of the NOS. At the same time, however, they were criticized for possessing a critical flaw described by Munby (1982) as "the doctrine of immaculate perception." That is, the use of Likert-type and/or multiple-choice format instruments assumes that both students and researchers interpret a given item in the same way. Aikenhead, Fleming, and Ryan (1987), however, indicated that student viewpoints on STS topics were not accurately captured by a Likert-type response format.

More recently, researchers tend to make more use of an interview in exploring students' views on the NOS. As Aikenhead et al. (1987) pointed out, interviews offer more lucid and accurate data concerning students' perspectives than traditional instruments (i.e., Likert-type and/or multiple-choice format instruments). In addition, interviews can enrich our understanding of the reasons and sources informing the beliefs that students hold and can lead us to a more comprehensive understanding of student perspectives (e.g., the limitations of the students' views and the way in which students' views affect their learning). However, interviews are not also without their own problems. The liabilities of interviews are the time and efforts needed to gather and analyze data. Therefore, especially in a large-scale survey, it would be almost impossible to adopt an interview as a method for collecting data.

Aikenhead, Ryan, and Fleming (1989) developed a new instrument, the views on science-technology-society (VOSTS), on the basis of extensive work over six years. The VOSTS consists of multiple-choice items in which a series of alternative position statements are provided. The most outstanding characteristic of the VOSTS is that the alternative viewpoints are derived from students' "self-generated" responses to avoid the problem of "constructed" responses (i.e., students and researchers do not necessarily perceive the meaning of a given statement in the same way) offered by most previous NOS instruments (Aikenhead & Ryan, 1992). In assessing students' views on the NOS, Solomon et al. (1996) also used students' self-generated responses as the bases of constructing alternative options for multiple-choice format items. An empirically developed multiple-choice format instrument has advantages over a traditional Likert-type instrument and/or an interview in the case of a large-scale survey. It reduces the ambiguity that exists in traditional instruments (i.e., students could differently perceive the meaning of a given statement) down to an acceptable level (Aikenhead, 1988). Furthermore, it reduces the time and effort needed for gathering and analyzing data in interviews. In this study, therefore, we decided to use an empirically derived multiple-choice format to examine students' views on the NOS.

Items used in this study were adapted with some modifications from Solomon et al.'s (1996) study (i.e., questions 1, 2, 3, and 4) and the VOSTS (i.e., question 5) in which empirically developed multiple-choice format items were successfully used. Although the items from previous studies had been carefully developed and validated, we were not confident of the effects of cultural differences on the validity of the items. Thus, special attention was given to modifying the items of previous studies. First, we checked the validity of the empirically derived options from previous studies. For this purpose, free writing was collected from a sample of 150 students who were asked questions used in previous studies. On the basis of the analyses of students' written responses obtained in this phase, we modified the wordings of options as well as the item stem of each question. In addition, we reduced the number of student position options in each item to three in order to avoid the potential problem concerned with the difficulties of students', especially 6th-grade students', reading and comprehending the questions. Three options for each item, of course, were selected on the bases of their frequencies obtained in this phase and their importance in revealing students' epistemological standpoints. We also included "other" as a final option in every item to eliminate the possibility of the "forced" answers for which many previous Likert-type and/or multiple-choice format instruments had been criticized.

Second, a first draft of the questionnaire was pilot tested for a sample of 100 students. In this phase, attention was especially paid to ascertaining whether the reading level was appropriate for use with 6th graders. Students were asked to underline the words and/or phrases that were difficult to understand. These words/phrases were revised with the help of three elementary school teachers. Finally, we interviewed several students, who are below the average achievement level in science, in order to verify the validity of the questionnaire. Only a few minor problems were detected in this phase. The questionnaire was thus appropriately modified through discussions with the elementary school teachers. The translation of items was finally checked by three independent experts fluent in English. The face validity of the questionnaire was also verified by a panel of experts consisting of three science educators and three science teachers. The final questionnaire is presented in Figure 1.

1. Scientists are those who are working on science. To put scientists' work in brief, it is . . .
   A. making new discoveries and adding them to the knowledge of nature.
   B. investigating natural phenomena and explaining the reasons for those phenomena.
   C. inventing things to make the world a better place to live in.
   D. Other
   (Explain) ____________________

2. What is a scientific theory? It is . . .
   A. a plausible but not yet completely proven fact.
   B. an explanation about the reasons for how things happen.
   C. a fact that has been proven by many experiments.
   D. Other
   (Explain) ____________________

3. Scientists think of all matter (solids, liquids, gases) as being made up of tiny particles. This is because scientists . . .
   A. can see the particles under a high performance microscope.
   B. have proven through many experiments that the matter is made up of particles.
   C. can explain the reasons for many phenomena by thinking of matter as being made up of particles.
   D. Other
   (Explain) ____________________

4. Many old scientific theories have been replaced by new ones. This is because . . .
   A. ways of explaining about the same phenomena have now changed.
   B. old theories have been proven wrong by the development of technology and the growth of knowledge.
   C. a lot of knowledge has been added to old theories. However, new theories are almost the same as old theories in essence.
   D. Other
   (Explain) ____________________

5. Gold-miners "discover" gold because gold was under the ground all the time to be uncovered. On the contrary, composers "invent" songs because they make the songs for the first time exercising their imagination. Then, do scientists discover or invent scientific theories?
   A. Scientists discover scientific theories. Though the scientific theories were there all the time to be uncovered, people did not know that before. Thus, scientists discover scientific theories.
   B. Scientists invent scientific theories. Scientific theories did not exist in the world and come from the imagination of scientists. Thus, scientists invent scientific theories.
   C. Sometimes scientists discover scientific theories, but sometimes scientists invent scientific theories.
   D. Other
   (Explain) ____________________

Figure 1. The final questionnaire.

Procedure

All students completed the questionnaire at the end of the school year. Students were informed before administrating the questionnaire that there were no right answers to any of the questions and that their course grades would not be affected by the results of the questionnaire. Students were asked to respond to an accompanying open-ended section for each item in order to collect information about the rationale(s) for their choices.

Since the data obtained in this study were not quantifiable, it was only possible to conduct the cross-tabulations between responses to the different options and to look for significance using chi-square statistics. Students' written responses to the open-ended section of each item were classified according to the rationales students conveyed. The coding scheme for students' responses was empirically derived through an iterative process—reading their responses, noting patterns, categorizing, and revising the categories. After a temporary coding scheme was agreed upon, two raters independently classified a subset of randomly selected responses. Discrepancies between the raters were then discussed and resolved. This discussion/resolution procedure was repeated before the intercoder agreement, calculated by computing a ratio of agreements to all codes in each item, reached 90%. Then, one rater classified all the responses again while the other rater independently checked the classification. Some students did respond to the questions but did not provide their rationales. The percentages of these students were 3.6–8.9% of those who had responded to respective questions. Because many rationales that students had provided were either reiteration or detailed explanations of the option that they had chosen, we presented some notable rationales, with the percentages of respondents, when they are different from the original meaning/intention of the options.

Findings

Purpose of Science

The first question concerning the purpose of science may appear to be rather distinct and distant from the other questions, which are related to an epistemology of scientific theories. As Ryan and Aikenhead (1992) asserted, however, students' images of science will certainly color their views on the epistemology of science, and vice versa. To know what students think science is, therefore, will help us gain a more comprehensive understanding of students' views on the NOS. The results of students' responses to question 1 are presented in Table 2. No statistically significant difference was found for the distribution of students' responses by grade level ($\chi^2 = 8.596$, $df = 6$, $p = .198$).

Table 2. Frequencies (and Percentages) of Students' Responses to Question 1

Option	6th Graders	8th Graders	10th Graders
A	96 (18.0)	94 (17.1)	83 (13.5)
B	76 (14.2)	99 (18.0)	97 (15.7)
C	318 (59.6)	318 (57.9)	388 (63.0)
D	44 (8.2)	38 (6.9)	48 (7.8)
Total	534 (100)	549 (100)	616 (100)

According to previous studies (Carey et al., 1989; Elder, 2002), recognizing that "the purpose of science is investigating natural phenomena and explaining the workings of the world" (option B) is considered as the best quality answer (at least for the elementary and middle school–aged students). In this study, however, less than 20% of the students were found to possess this contemporarily accepted perspective. Furthermore, when considering the rationales that students presented, the percentages of students who showed a sophisticated understanding fell even lower (6th graders: 6.4%, 8th graders: 10.4%, and 10th graders: 9.3%). That is, many of the students who chose option B did not support their choice with appropriate rationales. For example, some students (6th graders: 2.2%, 8th graders: 2.9%, and 10th graders: 2.6%) exhibited an instrumentalist (Barnes, 1985) or pragmatic perspective (see a later part of this section for more detailed characteristics concerning this perspective). They explained their reasons as "We have to know the reasons for natural phenomena *in order to use them in developing our society*," or "The duty of a scientist is investigating, proving, and explaining new facts and phenomena *for the prosperity of mankind*" (italics added by authors).

Fourteen to eighteen percent of students by grade level responded that "science makes new discoveries and adds them to the knowledge of the nature" (option A). These students consider science as a means through which knowledge about the world can be discovered, accumulated, and expanded. The tendency that students regard science as a process of discovering and collecting new facts has been also reported in many previous studies (Carey et al., 1989; Duveen, Scott, & Solomon, 1993; Elder, 2002; Solomon et al., 1996).

The majority of students, regardless of their grade level, were found to consider science as an activity concerned with making the world a better place to live in (option C). These students tended to think that science is valuable only when it contributes to the improvement of our lives. One 6th grader, for example, explained his reason as "If the purpose of science is accumulating knowledge or explaining the reasons for natural phenomena, our society could never have been developed as greatly as now. Because scientists should have stopped their works after they had found particular phenomena or had known the reasons of them." This pragmatic perspective—science as an instrument for social purposes—appeared to lead students into concluding that the major activities of science are making or inventing practical and useful things. One possible reason for students' instrumentalist perspective may be the confusion between science and technology. As science and technology become more developed and sophisticated in modern society, they should be more intertwined and dependent on each other. In addition, the mass media tend to report mainly the products of technology and/or applied science under the name of science (Ryan & Aikenhead, 1992). Therefore, when students are thinking about science, they are likely to have a technologically oriented image of science such as inventing artifacts, medical and environmental research, and genetic engineering, etc.

A number of previous studies have also reported that students tend to regard science as making or inventing something useful to improve the quality of our lives (Elder, 2002; Newton & Newton, 1992; Ryan & Aikenhead, 1992; Solomon et al., 1996; Stein & McRobbie, 1997). It has also been argued that seeing science in a technological light is more remarkable among younger students (Newton & Newton, 1992; Solomon, Duveen, & Scott, 1994). In the case of Korean students, however, the response tendency was rather different.

Solomon et al. (1996) reported that only 8% of British 10th graders exhibited an instrumentalist view of science and this view decreased as students got older. In comparison, the percentage of Korean 10th graders who possessed this pragmatic view (63.0%) was extraordinarily high in contrast with that reported in the Solomon et al.'s study. In addition, there was no remarkable change in the percentage of the pragmatic response across grades (see Table 2). These differences may be attributed to the characteristics of Korean culture. In Korea, like many developing countries, there has been a strong government policy concerning economic development. Science—to speak strictly, applied science and technology believed to bring more immediate results—has been emphasized as one of the most effective means to be an internationally competitive country. This "more science" policy might implicitly lead students to perceive a simple pragmatic relationship between science and society.

Definition of Scientific Theory

Scientific theories are the most important element of scientific knowledge and play a central, vital role in its growth (Duschl, 1990). However, it is a common mistake among students to equate scientific theory with scientific fact or even to think that fact is more important than theory. In question 2, we explored students' views concerning scientific theory. The results of students' responses to question 2 are presented in Table 3. A chi-square analysis on the distribution of students' responses detected no statistically significant difference ($\chi^2 = 11.007$, $df = 6$, $p = .088$).

Table 3. Frequencies (and Percentages) of Students' Responses to Question 2

Option	6th Graders	8th Graders	10th Graders
A	120 (22.9)	83 (15.1)	117 (19.0)
B	128 (24.4)	140 (25.5)	160 (26.0)
C	249 (47.5)	294 (53.6)	306 (49.8)
D	27 (5.2)	31 (5.7)	32 (5.2)
Total	524 (100)	548 (100)	615 (100)

About 25% of students in this study chose a contemporarily accepted epistemological viewpoint—"theory is an explanation about the reasons for how things happen" (option B). Considering the rationales that students presented, however, the number of students who possessed sophisticated views on scientific theories was substantially lower (6th graders: 13.2%, 8th graders: 13.9%, and 10th graders: 17.6%). Solomon et al. (1994) likewise indicated that they obtained a higher percentage of the "explanation" answers from a written questionnaire than they did from interviews. As Solomon et al. suggested, one possible reason might be the meaning of explanation in everyday language where it has vague and often diverse meanings. The term "explanation" is not often used as a strictly causal meaning in everyday talk. Requests for explanation—"why"—are commonly satisfied by the description of the same or another example so that students will describe rather than explain whenever it is easier to do so (Solomon et al., 1994). Furthermore, even in the school, the term "explanation" sometimes appears to be used quite differently in meaning from causality (Duveen, Scott, & Solomon, 1993). For example, "explain the procedure you used to carry out the experiment" is a common school instruction to students and may mislead them to regard an explanation as a mere description.

Fifteen to twenty-three percent of students by grade level were found to hold the view of "a plausible but not yet completely proven fact" concerning scientific theory. Previous studies have also indicated that this perspective, theory as a conjecture or an educated guess, is one of the most frequently held views by students as well as by the public at large (Duveen et al., 1993; Griffiths & Barman, 1995; Solomon, 1995; Solomon et al., 1996). Solomon et al. (1996), for example, reported that 46.5% of British 10th graders possessed this view. They suggested that this view might be due to another meaning of theory in everyday language. Based on the everyday meaning of theory, students tended to think that theory is an uncertain and unconfirmed opinion that would become a fact after scientists prove it. As a result, they are likely to have a hierarchical perspective concerning scientific knowledge from hypothesis to theory to fact/law/principle (Griffiths & Barry, 1993). Some students in our study also presented a similar perspective (6th graders: 14.3%, 8th graders: 7.5%, and 10th graders: 6.8%); "If you set up a hypothesis not yet clearly proven, it is a theory. After the theory is proven, it will become a law," or "If an idea was proven by experiments, it should be a law or a principle. But, if the idea has not been proven yet or it is impossible to experiment on it, we should call it a theory." Compared to the results of previous studies, however, the number of students who hold a conjectural view toward scientific theories was very small in our study. This may mean that Korean students do not place a characteristic of uncertainty on the term theory as much as do students in Western countries do. In the Korean culture, theory is a scientific term mainly used in science-related situations (e.g., science books/magazines/textbooks) rather than a common everyday word. Thus, the Korean students might be less likely to have a hierarchical perspective from theory to fact.

Some 8th (3.1%) and 10th graders (5.0%) explained their reasons for choosing a conjectural view as follows: "Scientific theories should change because many old theories have often proven wrong as time goes on. So, scientific theories are not proven facts," or "I think that scientific theories always change when scientists find something new. So, scientific theories are uncertain facts which are not yet completely proven." This perspective is noteworthy because it is based on an understanding of the changeability of scientific theories that is generally considered as an appropriate view on the NOS, at least, with respect to the tentativeness of scientific knowledge. These results suggest that to know that scientific theories could be replaced by new ones cannot always imply a sophisticated understanding of the NOS. In the discussion of the results of question 4, we will again deal with this point in detail.

The majority of the students who participated in this study possessed a view that "scientific theories are facts which have been proven by many experiments" (option C). Unlike the students in Western countries, the majority of whom considered theories as uncertain, Korean students tended to regard scientific theories as the truth or at least something very close to the truth. The response of a 6th grader clearly shows this view; "Science should be true. Scientific theories are those which are proven to get close to the truth through a lot of repeated experiments." Though limitations exist when exploring students' rationales using only their written responses, some students were nonetheless found to possess more sophisticated reasons. Some students (6th grade: 1.3%, 8th grade: 7.7%, and 10th grade: 4.6%) directly mentioned their school science experiences: “That is the reason why we learn science in the school. If scientific theories are not true, we don’t have to learn them in the school. Why do we have to learn the theories, if they would be replaced by true facts in the future?” “As described in science textbooks, all scientific theories have been proven to be true through experiments,” or “As we have learned in science classes, scientific theories are established after hypotheses were proven to be true.” As Hodson (1988) pointed out, it seemed that school science, which asks students to work without an understanding of the nature of scientific knowledge, strengthened students’ empiricist view on scientific theories. Some students, especially 10th graders, provided their rationales on the basis of a discrimination between hypothesis and theory (6th graders: 0.2%, 8th graders: 1.3%, and 10th graders: 3.4%): “Scientific theories are those which have been proven to be true whereas hypotheses are those which have not been proven yet,” or “Scientists continue to experiment to discover scientific theories. That is, they want to prove that their hypotheses are true.” Korean students, therefore, seem to hold hierarchical perspectives that run from hypothesis to theory (or fact) instead of those that run from theory (or hypothesis) to fact, a characteristic found in a greater measure among the students of Western countries.

Nature of Model

Although models of natural phenomena and theoretical constructs have been widely used as an instructional tool in science education, little is known about how students of different ages conceptualize the nature of models (Grosslight et al., 1991). In question 3, we explored students’ views concerning the nature of a scientific model, which is an important part of a scientific theory. The results of students’ responses to question 3 are presented in Table 4. A chi-square analysis indicated that there was a statistically significant difference on the distribution of students’ responses ($\chi^2 = 108.396$, $df = 6$, $p = .001$). More 6th graders tended to choose option A (i.e., we can see the particles), whereas more 8th and 10th graders tended to choose option C (i.e., we can explain the reasons for many phenomena through the use of a particle model).

Table 4. Frequencies (and Percentages) of Students’ Responses to Question 3

Option	6th Graders	8th Graders	10th Graders
A	119 (22.5)	64 (11.7)	52 (8.5)
B	281 (53.2)	276 (50.3)	275 (44.8)
C	83 (15.7)	182 (33.2)	241 (39.3)
D	45 (8.5)	27 (4.9)	46 (7.5)
Total	528 (100)	549 (100)	614 (100)

A good proportion of 6th graders as well as some 8th and 10th graders was found to have views of models that are basically consistent with a naive realist epistemology (option A). That is, they were more likely to think of models as copies of reality than as the constructed representations that may embody certain theoretical perspectives. For some students (6th graders: 1.5%, 8th graders: 0.7%, and 10th graders: 0.5%), experiences from their science textbook and/or mass media seemed to lead them to believe that models really exist: “In these days, technologies are so developed that we could see molecules. For example, I actually observed the cells of an onion through a microscope. So, we could also see the molecules of gas, liquid, and solid states if we should use a high-performance microscope,” or “TV programs showed us the microphotographs that most materials consist of molecules.” Sometimes students were convinced of the existence of models because they actually saw the models; “I think molecules do exist because I saw the microphotographs of molecules in my science textbooks.” That is, these students did not regard the microphotographs of molecules as another phenomenon that is consistent with a molecular theory, but instead, they view such microphotographs as decisive evidence for the existence of molecules.

Approximately half of the students, regardless of grade level, believed that models were proven to exist through many experiments (option B): “As I know, scientists don’t believe things that are not proven. In the same way, I don’t want to believe things that are not proven,” or “After a lot of experiments and investigations, scientists should have concluded that all materials consist of molecules.” These students seemed to believe that models (i.e., molecules in this case) exist regardless of whether they can see the models with their own eyes or not. The fact that they learned the models in science classes seemed to mean to these students that the models must be proven facts. Therefore, students who hold this view could also be regarded as having a naive realist epistemology. The results of this study are consistent with those of previous studies performed on students from Western countries. Grosslight et al. (1991) found that the majority of mixed ability 7th graders (67%) regarded models as copies of reality. Solomon et al. (1996) also reported that the majority of 10th graders (60%) and even about half of sixth-form students (aged 17–18) had this severely empirical stance. It is interesting that the majority of students from Western countries who possessed this empirical stance on models concurrently held a conjectural view on the question concerning theories. As discussed before, this inconsistent tendency may stem from the diverse meanings inherent to the term “theory.” Korean students, however, consistently show empirical stances on both theory and model unlike the students of Western countries.

Sixteen to forty percent of students across grades responded that scientists use models in order to explain the reasons for many phenomena (option C). In this question, unlike others, the number of students who held a perspective that could be regarded as consistent with a contemporary epistemological view, increased with age. At first glance, it seems that students exhibited more constructivist stances as they took more science classes. A possible explanation for this tendency is that the imaginary aspect of scientific theory might be effectively emphasized when students learned models. In many cases, models are described and explained through various analogies in order to help students easily understand them. Thus, students may have a more sophisticated understanding of the imaginary aspect of models as they learn more models in science classes. From a different standpoint, however, this interpretation is not consistent with the results obtained from the other questions in this study and the results of previous studies. Most 8th and 10th graders did not exhibit appropriate understanding in the other questions concerning theories (i.e., questions 2, 4, and 5 of this study). In addition, Grosslight et al. (1991) reported that even many honors 11th graders fundamentally regarded models as representations of real-world objects/events and not as representations of ideas.

The results of analyses on students' written rationales imply another possibility. Among those students who chose option C, only a few were found to have a sophisticated understanding of models (6th grader: 6.6%, 8th grader: 13.5%, and 10th grader: 15.1%). The remaining students (i.e., students who did not show any evidence of an appropriate understanding of models though they chose option C) tended to focus on other aspects of the question. For example, some students focused not on the nature/characteristics of general models but exclusively on the particle model (6th graders: 0.8%, 8th graders: 3.3%, and 10th graders: 2.9%): "Only when we think that all materials consist of particles, we can explain the changes of states of matter," or "Particles are the basic units of all materials. So, we cannot prove anything without the particle model." Compared with the others, this question was more specific by giving an actual example (i.e., particle model). This specificity might lead students to focus more on the usefulness of the particle model and thus result in a higher percentage of students. Ironically, Solomon et al. (1996), who originally developed this item, pointed out the risks concerning the situational effects that may influence students' thinking: "There would be little confidence, we thought, that what pupils said about one experiment would generalize to almost all experiments they were likely to encounter at school, unless the phrasing of the question indicated that the subject "experiment" or "theory" was general" (p. 495). Lederman and O'Malley (1990) also reported students' similar confusion when they used a specific example like atom in their interview question to explore students' views on models. Therefore, though there was a statistically significant difference across grades, it would be reasonable to interpret this result as a situational effect stemming from the greater specificity of this question.

Tentativeness of Scientific Theory

Theories change with new data and through scientists observing the world from different perspectives. Tentativeness is a primary attribute of scientific knowledge and an understanding of this tentative/revisionary nature has been regarded as one of the most important constituents of an individual's appropriate conception concerning the NOS. However, the results of previous research have been both disappointing and alarming to science teachers/educators. Students at all levels have consistently exhibited an inadequate understanding of the tentative nature of scientific knowledge (Lederman & O'Malley, 1990). The results of students' responses to question 4 are presented in Table 5. A chi-square analysis on question 4 indicated that there was a statistically significant difference on the distribution of students' responses ($\chi^2 = 78.107$, $df = 6$, $p = .001$). More 6th graders tended to choose option A (i.e., ways of explaining have changed), whereas more 8th and 10th graders tended to choose option B (i.e., old theories have been proven to be wrong).

Table 5. Frequencies (and Percentages) of Students' Responses to Question 4

Option	6th Graders	8th Graders	10th Graders
A	81 (15.5)	42 (7.7)	19 (3.1)
B	304 (58.1)	404 (74.1)	473 (77.2)
C	113 (21.6)	78 (14.3)	96 (15.7)
D	25 (4.8)	21 (3.9)	25 (4.1)
Total	523 (100)	545 (100)	613 (100)

Fourteen to twenty-two percent of students by grade level were found to possess a cumulative perspective on the change of scientific theories (option C). These students seemed comfortable with the cumulative perspective because it was in accord with their empirical stance that scientific theories/models are proven facts. For example, a 6th grader responded: "Theories just look like they have changed because new knowledge has been added to them. Theories cannot change. Because, if theories could change, it means either the old or new theory is wrong. It is impossible!" Some students rationalized their perspectives in more interesting ways. They tended to regard old theories as preliminary stages for new theories: "Wrong old theories are just the processes for discovering new theories," or "New theories are set by overcoming the defects of old theories. So, theories do not change but develop by adding more knowledge." To these students, changes in scientific theories seem to mean processes in which theories become progressively closer and closer to the truth and thus there may be no room for considering scientific revolutions.

The majority of students endorsed an idea that scientific theories develop over time. However, they saw changes in scientific theories as the results of falsifications by the development of technology and the growth of knowledge (option B): "Why do scientists change theories if theories are not proven to be wrong?" or "Obviously we now have better instruments and technologies than ever before. This is the very reason for the change of theories. Present theories could also be changed in the future as technologies develop." Duveen et al. (1993) also indicated that "better equipment/technology" was the most common rationale for students explaining the change in science. These results seem to be inconsistent with those obtained from other questions in this study, questions 2 and 3, in which the majority of students were found to have an empirical stance concerning scientific theories (i.e., scientific theories are proven facts). As Lederman and O'Malley (1990) pointed out, these inconsistent results might indicate that it is possible for students to compartmentalize their views with respect to aspects of the NOS or they might simply indicate that the students are in a state of transition.

Unlike the early studies on the NOS, which have generally reported students' poor understanding of the tentativeness of scientific theories, the results of some recent studies have reported an alternative tendency. Stein and McRobbie (1997), for example, reported that for older students (9th, 11th, and 12th graders) there was a clear indication of some modern philosophical perspectives being expressed concerning the tentative nature of scientific knowledge, whereas younger students (4th and 7th graders) did not indicate any recognition of the changeability of scientific knowledge. Tamir (1994) also reported that many 9th and 12th graders chose the desired answer concerning the tentative nature of scientific theories. Furthermore, Elder (2002) concluded that even 5th-grade students tended to regard scientific knowledge as a developing and changing construct, as opposed to other previous research conclusions. Do these results imply progress in students' understanding of the tentative nature of scientific knowledge due to the enormous efforts that have been exerted on explicitly teaching the NOS? On the contrary, however, there have also been many studies that reported a lack of students' understanding of the tentativeness of scientific knowledge (e.g., Griffiths & Barry, 1993; Ryan and Aikenhead, 1992; Solomon et al., 1996).

This inconsistency might be caused by the mechanisms used to measure students' views and to interpret their responses. As shown in this, as well as in many previous studies, a number of students tend to think that scientific theories do change. In the case of our study, students who reflected this reached nearly 80–90%. If one simply regards students' responses like "theories change over time" as indicative of a contemporary epistemological view, there will probably be an overestimation of the actual number of students holding tentative views on scientific theories. The overestimation would occur because all the students who just state their agreement with "the changeability of theories" would be considered as having an appropriate understanding regardless of their diverse rationales for stating so. Thus, if researchers would have considered students' rationales, they could have differentiated those students who did not possess the contemporarily accepted view even though they stated that theories do change. As Lederman and O'Malley (1990) assert: "The tentativeness of scientific knowledge is not limited to the recognition that scientific knowledge has changed through history. Rather, science draws its tentative and revisionary characteristics from a complex interaction of its assumptions, methods for developing knowledge, use and development of theories, and the undeniable limitations imposed on all human ways of knowing" (pp. 225–226).

As stated before, the results from question 4 indicated that more 6th graders had views consistent with a contemporary epistemology whereas more 8th and 10th graders had views which are based on traditional epistemology. Thus, at a glance, school science seemed to distort students' views on the tentativeness of scientific theories as many previous studies have suggested. The results of analyses on students' rationales, however, do not support this interpretation. After considering students' rationales, it was found that only a few students did possess a sophisticated understanding of the tentativeness of scientific theories (6th graders: 3.3%, 8th graders: 2.4%, and 10th graders: 1.1%). Many 6th graders who chose the desired option interpreted the meaning of it in diverse ways. For example, a few students thought that ways of proving natural phenomena had changed: "Modern scientists assert on the basis of experimental results while they did not know about the experiment in the past." That is, to speak precisely, these students' views were closer to an empirical stance. Therefore, it might be reasonable to conclude that the empirical stance is just as prevalent among 6th graders as it is among older students.

Origin of Scientific Theory

Scientific knowledge is not the result of a simple linguistic activity used to designate already organized facts about the outside world. Scientific knowledge is instead an instrument used to talk about specific interactions with constructed objects, and fundamentally it arises from this relationship (Larochelle & Désautels, 1991). However, scientific knowledge is so pervasive in our daily lives that ordinary individuals tend to take it for granted and not to cogitate on its very existence. In question 5, two camps within the philosophy of science were delineated: an ontological perspective consistent with logical positivism and an epistemic perspective consistent with a contemporary view (Ryan & Aikenhead, 1992). In order to help students interpret the differences between these two camps, we used two contrasting metaphors adopted from the VOSTS: "a miner discovers gold" and "a composer invents a song." The results of students' responses to question 5 are presented in Table 6. No statistically significant difference was found for the distribution of students' responses across grades ($\chi^2 = 7.070$, $df = 6$, $p = .314$).

Table 6. Frequencies (and Percentages) of Students' Responses to Question 5

Option	6th Graders	8th Graders	10th Graders
A	234 (47.1)	270 (50.2)	284 (46.6)
B	51 (10.3)	39 (7.2)	55 (9.0)
C	199 (40.0)	220 (40.9)	249 (40.9)
D	13 (2.6)	9 (1.7)	21 (3.4)
Total	497 (100)	538 (100)	609 (100)

Nearly half of the students across all grades had an ontological perspective concerning scientific theories. Generally, in the case of these students, theories are "out there" to be known by scientists. Scientists discover theories (i.e., facts) that already exist as objects. Theories are equivalent to a faithful description of a preorganized ontological reality independent of the observers (Larochelle & Désautels, 1991). Thus, of course, there was no students' understanding that theories are actually constructed ideas/explanations about natural phenomena. Students' written rationales clearly show this perspective: "Scientific theories exist from the first. If theories are imaginations which do not exist, they should not be called as theories. They must be just personal ideas," "Theories are just parts of the law of the great nature. It is probably a kind of nonsense to discover and prove something does not exist," or "In the past, scientists did not have technologies. But, modern scientists have great technologies so that they can discover new theories." It has also been reported by previous studies that a naive realism, which stresses a deterministic or positivist nature of the products of science, is the most common perspective among students (Carey et al., 1989; Stein & McRobbie, 1997).

At the other extreme, there existed an epistemic perspective consistent with a contemporary view. Consistent with the other questions asked in this study, however, only a few students were found to possess an appropriate understanding. In their study with Canadian high school students, Ryan and Aikenhead (1992) also reported that, even for 11th and 12th graders, students who had a purely epistemological view were only 17%.

Between these two extremes, there was another large group of students who viewed the emergence of theories either as the results of scientists' imagination or as those of scientists' discovery. Ryan and Aikenhead (1992) assumed that students holding this perspective were influenced by a classic but erroneous notion that many discoveries occur by accident, a notion heralded in the mass media and by popular writers of the history of science. However, the rationales that had led students to agree with this perspective were very diverse in our study. The majority of these students (6th graders: 27.4%, 8th graders: 27.7%, and 10th graders: 26.4%) thought that there are two kinds of theories. That is, they explained that the manner in which a theory emerges is dependent on the type it represents: "Sometimes we can hear from TV that scientists discovered fossils whereas sometimes we can hear that scientists invented speaking robots," or "Scientists discovered that the Earth rotates on its axis but they invented a microscope." For some students (6th graders: 4.8%, 8th graders: 5.6%, and 10th graders: 5.1%), scientific theories were considered as having the attributes of both discovery and invention: "Generally scientists discover theories but they add their imagination to the discovered theories," or "There are many theories in nature but those who discovered them are scientists. So, scientific theories have both characteristics." Finally, some other students (6th graders: 1.6%, 8th graders: 2.0%, and 10th graders: 2.8%) thought that the problem of discovery or invention depends on the time in history in which the theories emerged: "In the past, science was not so developed as now. So, theories were discovered in the past whereas they are invented now," or, to the contrary, "Modern scientists have a lot of knowledge so that they discover theories with various methods. Whereas past scientists did not have much knowledge so that they could not help but conjecture, that is, invent theories."

Clearly, most of these students choosing option C interpreted the term "invention" far differently from a contemporary epistemological view. Furthermore, like those who chose option A, these students basically acknowledged the discovery nature of scientific theories and just added some variations to this discovery perspective. Therefore, it might be reasonable to regard that these students' perspectives are actually far closer to an ontological view than a simple analysis might lead us to suspect.

Conclusion

Although the generalizability of this investigation might be limited by the sample size and student background (i.e., all students were sampled from a Korean metropolitan city), these results should be potentially useful to a wide range of science teachers/educators in that the data revealed perspectives harbored by typical Korean elementary school students as well as those in middle and high schools. The results of this study can provide baseline data for the designs of science lessons, units, and/or curricula.

Our results are not encouraging, but neither are they surprising, when considered against the backdrop of results from previous studies. It became apparent that the students participating in this study possessed views about the nature of scientific theories that are not consistent with a contemporary epistemology. In all questions, only a small number of students, regardless of grade level, were found to have an appropriate understanding of the NOS. It is noteworthy that even 10th graders still need further development of their views on the NOS because 10th grade may be the final year of formal science learning for approximately half of the Korean school-aged population. Thus, for 10th-grade students, the views expressed here may represent those views on science they will continue to hold in their everyday life after formal schooling has been completed. If it is not a false belief that scientific literacy is a necessity to survive in an increasingly scientific and technological society and that one's ability to become scientifically literate is greatly impaired when the NOS is not completely understood, then more attention should be paid to teaching the NOS. The results of this study indicated that even 6th-grade students did possess their own epistemologies, which was consistent with our assumption. Although there were a few indications of the confusions for using certain terms like "explanation" and/or "invention," 6th graders' rationales for the choice of a particular option, on the whole, clearly showed their perspectives about the NOS. Furthermore, 6th graders' views on the NOS were quite similar to those of 8th and 10th graders. These results are noteworthy considering the science curriculum of an elementary school. Like those of other countries, the science curriculum of Korea relatively emphasizes factual knowledge and basic science concepts at the elementary school level. As a result, compared with middle and high school students, elementary school students do not have as many opportunities to experience an inductive approach, which has been designated as one of the major sources for students' inappropriate understanding of the NOS, in science classes and/or textbooks for introducing scientific theories. Although the reason is not clear at present, it is apparent that elementary school students already possess a distorted view of scientific knowledge. Therefore, it may be more productive to teach students about the NOS at the elementary school level than to remedy secondary students' inadequate understanding.

As stated above, there were no clear differences among 6th, 8th, and 10th graders' perspectives about the NOS. These results seem to indicate that science experiences at the secondary level can exert little influence on the development of students' views and merely support and maintain students' naive views during their school years. In responses to some questions, however, students' rationales indicated several influences of school science on their perspectives. Experiences from science classes and/or textbooks (e.g., ways to prove a hypothesis, observing microphotographs of molecules, etc.) appear to strengthen students' empirical stance. Therefore, at least at present, it is difficult to draw a definite conclusion concerning the influence of school science on students' views. In order to get a comprehensive understanding of this relationship, further study is needed.

While previous studies performed in Western countries had much in common with this study, there also existed clear differences between respective students' views on the NOS. These differences stemming from cultural characteristics should never be disregarded, because any such difference may make curricular materials designed to modify students' views on the NOS in one culture, ineffective in another (Newton & Newton, 1992). Efforts to differentiate the meanings of theory in everyday and scientific situations, for example, may be effective for the students of Western countries in developing their understanding of the nature of scientific theories. These same efforts, however, may be less effective for Korean students because they are inherently less likely to have such a confusion about the meaning of theory. Instead, more intensive efforts should be exerted on the Korean students concerning the explanatory nature of a scientific theory because the majority of them possess an empirical stance on the NOS.

Finally, it appears that more care should be taken in the assessment of students' views on the NOS. Although the empirically developed multiple-choice format we used in this study reduces the ambiguity inherent to traditional Likert-type or multiple-choice format, the potential for misinterpretation still exists. Many students' responses to the question concerning the nature of models, for example, could have been regarded as a contemporarily accepted epistemological view, if we had not considered their written rationales. Students' perspectives about the changeability of scientific theories could also have been interpreted either as a contemporarily accepted view or as a naive one according to whether students' rationales for their choices had been or had not been considered. As Lederman and O'Malley (1990) pointed out, language is often used differently by students and researchers and this mismatch could certainly lead us to misinterpret students' views. Therefore, although a quantitative method is an inevitable option especially in the case of a large scale investigation, it should be supplemented by some forms of qualitative methods—like an interview or, at least, a written rationale section—in order to avoid a misinterpretation of students' views.

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