

# An Analysis of Scientific Epistemological Beliefs and Learning Orientations of Taiwanese Eighth Graders

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**ABSTRACT:** The purpose of this study was to acquire a better understanding of the interaction between scientific epistemological beliefs and learning orientations in a group of Taiwanese eighth graders. After analyzing questionnaire responses of an initial sample of 202 students, 20 information-rich students were selected as the final subjects for this study. A qualitative analysis through interviewing of the subjects revealed that students holding constructivist epistemological beliefs about science (knowledge constructivists) tended to learn through constructivist-oriented instructional activities, and employ a more active manner as well as more meaningful strategies when learning science, whereas students having epistemological beliefs, more aligned with empiricism (knowledge empiricists), tended to use more rote-like strategies to enhance their understanding. Knowledge constructivist subjects tended to have more pragmatic views about the value of science and they were mainly motivated by their interest and curiosity about science, whereas knowledge empiricist subjects were mainly motivated by performance on examinations. This article suggests the importance of presenting the constructivist philosophy of science for students. It follows that students are expected to have more meaningful orientations, as well as more appropriate attitudes, toward learning science. © 1998 John Wiley & Sons, Inc. *Sci Ed* 82:473–489, 1998.

## INTRODUCTION

Educators have lamented that students tend to use rote memorization when acquiring school knowledge (Perkins, 1992), in particular when learning science (Roth, 1989), and what they have gained is a shaky knowledge of scientific concepts. Science educators have advocated so-called “meaningful learning” for quite some time (e.g., Ausubel, 1968; Ausubel, Novak, & Hanesian, 1978; Novak, 1977). Many agree that meaningful learning for students could produce better cognitive outcomes, allow for more integrated knowledge structures, and foster greater learning motivation. Consequently, researchers have recommended many teaching strategies to promote students’ meaningful learning (e.g., Anderson, 1987; Minstrell, 1989; Novak & Gowin, 1984); however, not all of these are successful (Donn, 1990; Lehman, Carter, & Kahle, 1983). To discuss the contributory variables for the fragmentary nature of students’ science learning and their rote

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learning strategies, we seldom ask a very fundamental question: What are the students' views about the nature of scientific knowledge?

[I]f scientific knowledge is thought of as infallibly arising from observation, a person might study science by memorizing facts and might further expect to be able to absolutely prove hypotheses by the scientific method. (Waterman, 1983, p. 301)

If a person thinks of science as an ongoing process of concept development, he or she might [focus on] concepts and their variants. (Waterman, 1982, p. 5)

Students' *scientific epistemological beliefs* (SEB) may shape their metalearning assumptions and thus influence their learning orientations. Science educators have identified an individual's SEB as an essential feature of his or her conceptual ecology (Demastes, Good, & Peebles, 1995; Hewson & Hewson, 1984; Posner, Strike, Hewson, & Gertzog, 1982; Strike & Posner, 1985). These beliefs are also related to the kinds of strategies or types of problem-solving decisions used to analyze anomalous data during the process of scientific knowledge construction (Chinn & Brewer, 1993), or they are correlated with students' cognitive structure outcomes (Tsai, in press). This research was an attempt to further explore the interplay between students' SEB and their learning orientations. Although there might be some earlier research projects investigating similar topics (e.g., Edmondson, 1989; Hammer, 1995), they were all conducted in Western cultural contexts for older learners (e.g., college students). This study, conducted with Taiwanese eighth graders, could be viewed as the first attempt in an Eastern country to analyze the SEB of students in lower grades and their learning strategies.

## METHODOLOGY

This study was conducted in a large urban junior high school near Taipei City, Taiwan, with a population of about 5000 students. The eighth grade level consisted of 37 classes with an average of 50 students in each class. Four average-achievement classes, ranked between 12th and 25th among these classes in schoolwide formal science tests, were selected as an initial pool of students for this research, a total of 202 eighth graders. These classes were taught by four different science teachers. These teachers, however, had similar educational backgrounds; they graduated from the same teacher-training university with a major either in physics or chemistry. They had teaching experience ranging from 8 to 15 years, but only one was female. Their teaching style was traditionally oriented, the same as in most Taiwanese science classrooms. Taiwan uses strictly a nationwide curriculum for every course in elementary and secondary education. Eighth grade is the first time these students receive formal instruction about physical science. Before this study was conducted, they had already learned the concepts about mass, volume, density, force, buoyancy, pressure, temperature, heat, air pressure, combustion, and carbon dioxide, and some basic ideas about elements and compounds.

To choose appropriate information-rich subjects for this project, the following criteria were employed to filter such students: (1) they were above-average achievers; and (2) they expressed a strong *certainty* and clear *tendency* regarding their SEB based on questionnaire responses (Pomeroy's questionnaire, 1993). This set of criteria was used because the students would be expected to have proper self-awareness about their learning orientations as well as their SEB. Students' science achievement was represented by their scores on two schoolwide science examinations. A Chinese version of Pomeroy's (1993) questionnaire was administered to assess students' certainty and tendency regarding SEB. The questionnaire consists of bipolar agree–disagree statements on a 5–1 Likert scale, ranging from empiricist to constructivist views about science. The empiricist views about science tend to support that: (1) scientific knowledge is unproblematic and it provides *right* answers; (2) scientific knowledge is *discovered* by the *objective* data gathered from observing and

experimenting or from an universal scientific method; (3) scientific knowledge is additive and bottom-up, and evidence accumulated carefully will result in infallible knowledge (Carr et al., 1994; McComas, 1996; Strike & Posner, 1985), whereas the constructivist views assert that scientific knowledge is *constructed* (or *invented*) by scientists, its status is tentative, and its development experiences a series of revolutions or paradigm shifts (Tsai, 1996a). The final questionnaire for this study was developed by selecting Pomeroy's items representing "traditional views of science" (empiricist views) and "nontraditional views of science" (constructivist views), a total of 17 items. Pomeroy (1993) reported that the reliability for these two parts was moderately high (Cronbach's  $\alpha = 0.651$ , and  $0.591$ , respectively). The following two statements are sample items, cited from the questionnaire:

1. Science is the ideal knowledge in that it is a set of statements which are objective; that is, their substance is determined entirely from observation (identified as traditional or empiricist views).
2. Nonsequential thinking, that is, taking conceptual leaps, is characteristic of many scientists (identified as nontraditional or constructivist views).

To assess respondents' certainty or confidence about their SEB, after making a choice for each question, they were asked to answer the following question: "Concerning this choice, I am: (1) guessing, (2) uncertain, (3) fairly certain, (4) sure." The questions that elicited responses of "fairly certain" or "sure" were viewed as *confident* items, and the students with over three quarters of items in the questionnaire identified as *confident* were viewed as appropriate subjects for this study.

Students' responses to *confident* items on Pomeroy's (1993) questionnaire (i.e., showing students' strong certainty) were scored as follows to test their tendency of SEB. For the "constructivist perspective" items, a "strongly agree" response was assigned a score of 5, and a "strongly disagree" response was assigned a score of 1. Items representing an empiricist view were scored in a reverse manner; that is, a "strongly agree" response was assigned a score of 1, and a "strongly disagree" response was assigned a score of 5. Thus, on the total questionnaire, students having strong beliefs about constructivist views would have higher average scores. By and large, this study examined a one-dimensional assessment of students' SEB; namely, a continuum from empiricist to constructivist views.<sup>1</sup>

Among those who were above-average achievers, and had a strong certainty of SEB, the following subjects were finally chosen for this study: six were randomly selected from the students who scored in the top 15% of Pomeroy's questionnaire; eight were selected from the average group (those scoring most close to the mean of the subject students—in general, those holding both empiricist and constructivist views about science); and six were randomly selected from the bottom 15% group. Such a selection strategy corresponds to Patton's "maximum variation sampling" method for qualitative research (Patton, 1990, p. 172) and they were supposed to possess a clear tendency of SEB. As a result of this study, the first group, which could be viewed as a "knowledge constructivist" group (in Hashweh's [1996] terminology), included three males and three females;

<sup>1</sup> A pilot study conducted with another group of Taiwanese eighth graders was used to assess the reliability of the Chinese version of Pomeroy's questionnaire. Because there were missing data for students' questionnaire responses (i.e., those without students' confidence), this study could not properly conduct an  $\alpha$  reliability test to assess the questionnaire's internal consistency. This study finally used the correlation coefficients between the student's response on every individual item and his or her average score on all confident items to assess the consistency of this questionnaire. Except for one question, which was excluded from final analyses, the correlation coefficients (ranging from 0.43 to 0.67) were significant at the 0.05 level, indicating that the Chinese version of Pomeroy's questionnaire showed satisfactory internal consistency in assessing students' SEB (Tsai, 1996a).

the second group, which could be viewed as a “mixed” group, included five males and three females; and the final group, which could be viewed as a “mixed” group, included five males and three females; and the final group, which could be viewed as a “knowledge empiricist” group, included four males and two females. Each of these groups included a variety of science achievers, ranging from average to high. In fact, a relatively large-scale study completed in the same school revealed that there was no statistically significant correlation between students’ SEB orientations and science achievement ( $r = 0.04$ , NS,  $n = 48$ ; see Tsai, [in press]). The finally selected subjects were interviewed regarding their beliefs about science and their learning orientations. The interview was conducted independently for each subject by the same researcher (the author). These in-depth interview data yielded the research foundation for this study. Numerous educators have proposed the use of interviews in assessing students’ SEB (e.g., Ginev, 1990; Lederman, 1992; Lederman & O’Malley, 1990). A concise framework of interview questions used in this investigation is presented in the Appendix, many of which were cited from earlier studies (Carey, Evans, Honda, Jay, & Unger, 1989, p. 528; Edmondson, 1989, p. 78; Lederman & O’Malley, 1990, pp. 227–228). The research themes and qualitative interpretations presented in this article were based mainly on this interview framework.

All of the interviews were tape-recorded. Because the interviews were conducted in Chinese, all of the data were transcribed after the author’s translation. These translated data, constructing the research base for qualitative interpretations, were examined by a second independent speaker of Chinese, who actually listened to the entire set of interview tapes. It should be noted that, at the time of transcribing and synthesizing subjects’ qualitative details, the researchers did not know every subject’s particular SEB position, as assessed by Pomeroy’s (1993) questionnaire.<sup>2</sup>

## RESULTS AND DISCUSSION

To help readers understand the following data and discussion, each interviewee is given an identification, including two letters and one number. The first letter indicates his or her epistemological orientation based on his or her responses in Pomeroy’s (1993) questionnaire: C for the knowledge constructivist group; M for the mixed group; and E for the knowledge empiricist group. The second letter shows his or her gender, M for male and F for female. A following number is a sequential identifying number for each individual in a group. For instance, CM1 means that the interviewee is a male student with SEB close to constructivist views about science.

After examining the students’ in-depth interview data, it was found that most of the students, either knowledge constructivists or empiricists, believed that science was discovered, not invented by people, similar to a finding revealed in Ryan and Aikenhead’s study (1992). This may result from the fact that science is always shaped as a process of discovery of truth by traditional science education or by the public. Besides this point, only one female student, categorized as a knowledge empiricist in Pomeroy’s questionnaire, likely held mixed SEB (EF4) and one male student, labeled as a mixed epistemology holder, was likely a knowledge empiricist (MM4). Such a high consistency between quantitative results and qualitative details may come from the fact that extreme cases were selected for this study. In what follows, subjects’ interview data of SEB will be presented first and then their learning orientations will be discussed. Moreover, after reviewing mixed SEB subjects’ interview details, it was generally found that their results were either the same as those of (knowledge) constructivist subjects, or as those of (knowledge) empiricist subjects, or as a combination

<sup>2</sup> The subjects’ science teachers were also interviewed about their SEB position. It was found that one of them (a total of four) was likely a knowledge empiricist and the rest of them tended to have mixed SEB. However, these teachers’ SEB may not have had a major effect on students’ SEB due to the fact that they merely taught these subjects for about 3 months when conducting this study. Students’ prior experiences (e.g., from media or the science teachers in their previous grade levels) may be more important in accounting for their SEB variations.

of both views. However, constructivist learners' responses, in most cases, are very different from those of empiricist learners. As a result, this study focuses mainly on the comparisons between constructivist and empiricist students. This could be viewed as purposeful sampling, which intends to capture and describe the central themes and principal outcomes that cut across a great deal of participants and variations (Patton, 1990). That is, to acquire a clear account about the interplay between students' SEB and their learning strategies, the present results will basically contrast the responses revealed by constructivist students and those stated by empiricist students.

### Students' Scientific Epistemological Beliefs

When asked "what is science?" and the characteristics of scientific knowledge, constructivist students tended to believe that science was an imaginative activity conducted by people, or science was something closely related to our everyday lives, whereas empiricist students tended to assert that science was a collection of correct facts:

R (researcher): If someone asks you "what is science?," what will you tell him or her?

CM1: Science is like a kind of magic. People use their imagination to propose scientific theories.

CF2: Science is an activity not limited by others' ideas but it already exists in the world, in nature.

CF3: Science exists in our everyday lives. Also, science is presented in different ways. We can use words, numbers, figures, symbols to represent science . . . It is a way of communication.

CM4: Science is a kind of knowledge of researching, discovering, exploring, and thinking.

EF1: Science is modern. It is correct. It is proposed to break the myth.

EM2: Science is the knowledge that has been proved by experiments. It makes our lives more convenient.

EM3: Science is a logical and systematic collection of facts occurring in nature.

EF4: Science explains the causes of natural phenomena. It is discovered by a group of scientists and then they tell everyone.

MM1: Science is a collection of laws proposed by scientists.

MM2: Science is a study of something unknown. It is used to break the myth, that is not supported by scientific evidence.

When asked "what are the characteristics of scientific knowledge," constructivist subjects greatly emphasized the tentative nature of scientific knowledge, whereas empiricist students tended to highlight the validity and accuracy of scientific knowledge:

R: What are the main characteristics of scientific knowledge or what are the differences of scientific knowledge and other kinds of knowledge?

CM1: Well, language and history is static but science is dynamic. Also, science is more related to our real life and it is changing all the time.

CM4: Science is always discovering something new. Other knowledge, for example, language, if it is accepted by the public, it does not change any more. Science can be changed and it can be used to solve real-life problems.

CM5: Science is very dynamic and it is changing all the time. The scientific knowledge proved by a group of scientists is not always correct. It will change after a series of people's thinking and experiments.

EM2: Science is supported by actual experimentation, not just people's thinking or words.

EM5: Science is a kind of knowledge emphasizing the accuracy, the exactness. It provides the very details for everything. In science, you cannot use an approximation, or a rough estimation. . . . Science does not come from pure thinking; it comes from actual doing or operation. You cannot propose any scientific theory or law simply by your own thinking or ideas.

MF3: Science is universal. It uses symbols to represent ideas, no matter what background you are.

According to students' responses, empiricist subjects stressed the important role of (precise) experimental evidence in science. On the other hand, constructivist students viewed the dynamic nature of scientific knowledge as among its main characteristics. Later, when asked the sources of scientists' ideas, constructivists tended to believe that scientists' ideas came from their intuitions or flashes of insight (five of six students), the theories proposed by earlier scientists (three of six), and even ancient folklore (two), but *none* of them mentioned anything about observations. Although constructivist students respected scientists' personal intuitions, they still considered the influences of earlier or current theories on the development scientists' ideas. One constructivist student (CM5) responded that, "although scientists use their intuitions [when proposing scientific theories], they cannot propose any theory they want; they have to check if their ideas conflict with existing theories." On the other hand, although three of the six empiricist students believed that scientists' intuitions play a role in their ideas, many of them viewed careful observations as the main sources of scientists' ideas (four of six).

Students' responses on how scientists did with their ideas also clearly differentiated their SEB. Although most of them thought that scientists would conduct some experiments to test their ideas, constructivist students tended to believe that scientists did not have a certain method or a series of procedures in doing science, whereas empiricist subjects tended to value the validity of codified procedures of the "scientific method" (except EF4):

R: Do scientists do anything with their ideas? How?

CM1: They rely on their intuitions and ideas to discover what they believe to be. (R: By what method?) Experiments or discussions with other scientists.

CF6: They would do some experiments or check other resources [to test their ideas]. (R: How do they do it? Do they have a certain method?) No, the method is decided by them. Every scientist can have different methods to test their ideas.

CM5: They would check if earlier scientists had similar ideas. You know, scientists, more or less, are influenced by earlier scientists.

CF3: They will set up their research questions first, and then do some experiments or research. (R: Do they have a certain method or procedure?) I don't think so. Because every scientist has different ideas, they employ different procedures when testing different theories.

EM5: They will conduct experiments and make observations to test their ideas. (R: Do they have a certain method or procedure when doing this?) Certainly! If they do not follow a certain method or procedure, other scientists would not believe the results. The method can ensure the accuracy of the results.

Furthermore, students were interviewed about how it is possible for scientists to propose totally different theories to describe the same phenomena.

R: Some astrophysicists believe that the universe is expanding, while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data (or they are looking at totally different data)?

CM1: That's because they use different data or different theories when studying this issue.

CF3: When scientists conduct experiments or make observations, their ideas are involved in their experiments and observations. Therefore, they can have quite different theories. But I think it is difficult for us to decide which one is correct and which one is wrong. . . . Observations do not always show the exact truth or the reality. Scientists select those observations which favor their theories.

CF6: . . . I think they are looking at similar data. But, in fact, science is not the correct answer. So, everyone can have different views to see it, and then get different theories.

EM2: That's because they do not collect enough evidence. They just depend on partial observations and then draw conclusions.

EF4: They are looking at different data, and then have different findings.

EM6: Someone must make some mistakes. There are some errors for every observation. Our modern technology still cannot measure or observe everything precisely. If we can have one 100% correct instrument, this would not happen.

According to students' responses, constructivist students tended to believe that the existence of different theories came from the variety of theories taken by scientists. For them, there was no clearly correct answer and we can understand natural phenomena through different but valid perspectives. However, empiricist subjects tended to insist that there was one correct answer for this, whereas the existence of different theories came from the limitations of technology or inadequate observations. In other words, the SEB held by constructivist students were similar to the "knowledge problematic" epistemology defined by Carey and Smith (1993) that our knowledge is elusive and uncertain and it is judged to be more or less useful, not strictly right or wrong, whereas the SEB held by empiricist students were close to the "knowledge unproblematic" epistemology proposed by Carey and Smith that, when individuals have different opinions about something, it is possible that only one of them is right; false beliefs are caused by ignorance, misinformation, or fraud. A similar epistemological dichotomy is reflected also by students' responses about what condition causes the change of scientific theories, although most students believed that science would change. For example:

R: After scientists have developed a theory, does the theory ever change? Why (when, how) or why not?

CM4: Yes. . . . But the old theory is not totally wrong. Otherwise, it cannot be accepted for a long time. It still can be used in some special situations. . . . The new theory, I think, should be more powerful or more convincing to explain something.

CM5: If the theory is not accepted by most scientists, it will change. In science, if someone proposes a theory that receives agreement among the majority of scientists, it will be a better theory.

EM2: When scientists find that the earlier experiments are incomplete or incorrect, the theory will change. Or, scientists get some experimental results that conflict with the theory, and then the theory will change.

EF4: If modern technology improves the accuracy of experimentation, the theory would change.

By and large, constructivist students believed that the power or potential and the acceptance of a new theory caused theory changes in science, whereas empiricist students asserted that the evidence and the correctness engendered changes of scientific theories. The empiricist students shared the same views as the college subjects in Waterman's study (1983) in that they showed the convictions for the tentative nature of science, but they thought that this tentativeness came from the limitations of technology and sensory limits. Thus, when advanced technology was available, one could approach the truth; therefore, this belief still describes the traditional empiricist position.

This selected group of students, through in-depth interviews, clearly expressed their SEB. This

concur somewhat with the conclusion drawn from the study conducted by Laroche and Desautel (1991) that “[w]hether we like it or not, or we are conscious of it or not, adolescents construct, especially in the context of their science education, representations of the nature of science” (p. 382).<sup>3</sup> These students’ SEB, basically, can be explained by a continuum ranging from empiricism to constructivism. In the following, the interplay between students’ epistemological beliefs about science and their learning orientations was explored. Again, it focused on contrasting the learning orientations between knowledge constructivist students and knowledge empiricist students.

### **Interplay between Students’ Scientific Epistemological Beliefs and Their Learning Orientations**

First, when students were asked to describe an ideal environment of learning science, constructivist students tended to emphasize the opportunities to discuss with others, to solve real-life problems, and to control their own learning activities. On the other hand, empiricist students tended to stress the clarification of teachers’ lectures when responding to the same interview question:

R: Describe [or imagine] a science classroom situation [including the teacher and students] where you felt [or feel] as though you were [or are] really learning or you could learn best?

CM4: Well, science is a subject that focuses on the application of real-life problems, and concrete operations. We cannot learn science only from textbooks. Therefore, we have to actually do some lab and know the applications of scientific concepts in our everyday lives.

CM1: The teacher should be flexible in teaching. The teacher and students should cooperate with each other and enjoy studying something together. Students, as small groups, should discuss together and then tell the teacher their ideas or conclusions. Then, the teacher can adjust our ideas. He [or she] cannot just tell us the final answer.

CF3: Teachers should tell us just the big ideas. The rest of the ideas should leave to us to explore by ourselves. Teachers should give us opportunities to discuss the ideas and they also should give us enough time to conceptually understand these ideas.

EM2: The teacher should try his [or her] best to explain his [or her] ideas as clearly as possible.

EM3: The teacher should tell us very clearly what to memorize. Also, we should have very good textbooks.

EF4: The teacher cannot just show us how to calculate the formulae or how to solve the problems. He [or she] has to clearly explain why he [or she] was using such a method or formula to solve the problems. In this way, we can solve other problems later.

EF1: Students should discuss the topics amongst each other because students, in general, are afraid of asking the teacher questions. You know, we are afraid of making mistakes when the teacher is present.

Because empiricist students believed that science was a collection of correct facts, it was plausible for them to think that they could learn best when teachers could clearly present their ideas. Also, they seemed to show the anxiety of making mistakes (e.g., EF1) and to rely on the role played by the teacher, implying that they tended to employ a passive manner in learning science. On the other hand, constructivist subjects tended to agree that they could learn best by discussing with others and, to a certain extent, constructing their own knowledge, possibly because they believed that science was constructed by people’s negotiation and human decision making. This confirms a quan-

<sup>3</sup> It should be noted that the final subjects involved in present study were students with strong certainty about their scientific epistemological beliefs; hence, this study has limitation to draw the conclusion as proposed by Laroche and Desautel (1991) that adolescents, in general, have already constructed their own epistemologies of science.

titative finding revealed in Tsai's (1997) investigation that students having SEB more aligned with constructivism showed a greater preference to learn through constructivist learning environments (e.g., interacting with others' ideas, integrating their prior knowledge, and meaningfully controlling their learning activities) than those holding SEB more oriented to the empiricist epistemology.

When students were interviewed about their responsibilities as students, constructivist students tended to view that to think deeply (four of them), to apply what they learned in everyday life (three of them), and to ask questions immediately if they did not quite understand (two of them) were their responsibilities of learning science. On the other hand, empiricist students tended to assume that to listen carefully in classes (four of them) and to do more problem-solving practices (three of them) were their responsibilities. Empiricist students showed a learning belief that conceptual understanding was associated with an ability to master the details of a prodigious amount of scientific ideas or to solve stereotypical tutorial problems, a finding similar to that suggested in Linder's study (1992). This further implied that constructivist students tended to employ more meaningful learning strategies in learning science, whereas empiricist subjects may have taken a rote learning orientation. Their responses about the ways they checked whether they had already known some scientific concepts supported this interpretation:

R: How do you ensure that you already know something? For example, when you learn the concept of "density," how do you ensure that you have already understood the concept of density?

CF2: Not only should I understand the concept but I can also explain the concept to others. If I can do this, I am quite confident that I have already understood it.

CM5: My ideas are very consistent. There is no conflict among the ideas in my mind. Every idea should be very consistent.

CF3: I can solve all of the problems about the concept of density without referring to the solutions provided by textbooks or reference books. I use the key concept, not memorization, to solve the problems. If I can do so, I think I have already understood it.

CM4: First, I can use two or three methods to solve the same problem. And then, I can tell other students how to solve it, not just the problem-solving procedures.

CM1: In general, there is more than one correct solution for a problem. If I can use different methods to solve it, I think I understand the concept.

Here, constructivist students revealed many meaningful learning strategies in learning science. First, they tried to explain to others what they had already known (e.g., CF2, CM4). The interaction with others was a key way for them to ensure their understanding. Second, they showed higher metacognitive skills to monitor the construction of their ideas. For example, CM5 believed that one should make all of one's ideas consistent if the idea is to be conceptually understood. Third, they took a more active approach to learning science; for example, CF3 tried to solve all of the problems by herself without referring to the solutions offered by textbooks or reference books. That is, she intended to meaningfully control her learning activity. Fourth, they tried to use different methods to solve the same problem (e.g., CM4, CM1); in this way, they can acquire "cognitive flexibility," helping them to transfer some knowledge gained from oversimplified cases to conceptually complex situations (Spiro, Feltovich, Jacobson, & Coulson, 1992). Their constructivist views about science may induce these learning orientations. For example, constructivist students believed that we can have different but valid perspectives to explain the same phenomena; hence, they may try to use different methods to solve the same problem.

Only one constructivist student simply used the capability to successfully solve numerous stereotypical tutorial problems as the criterion to assess her understanding. However, empiricist students

tended to use their performance on examinations and the ability to solve various tutorial problems as criteria to evaluate their understanding. For example:

R: How do you ensure that you already know something? For example, when you learn the concept of density, how do you ensure that you have already understood the concept of density?

EF1: If I get a pretty good grade on the exam, I think I quite understand the concept. (R: What does it mean by a pretty good grade?) I think, in general, above 80 [on the basis of 100].

EM2: If I finish practicing all of the problem sets or the tutorial exercises in the resource books and there is no serious difficulty for me to solve them, I am sure that I have already understood it.

EM5: If the problems about the concept of density are given to me and then I can quickly know how to solve them, this means that I have already understood it.

EM6: I can understand what the teachers say in classes and if classmates ask me some questions; I can answer their questions. Then I think I have understood the concept.

In fact, the rest of the empiricists had similar responses to those just presented. With the exception of EM6, who mentioned interaction with other students, the selected empiricist students tended to use their ability of solving tutorial problems or their test scores as the key factors in measuring their understanding. The idea that science is a collection of correct facts, again, may have convinced them to practice intensively (perhaps, rote) to ensure their understanding. That is, they tried to familiarize these facts by repeated problem-solving practices or perhaps rote memorization. This finding supports that constructivist subjects tended to have achieved the second level of cognitive processing, categorized as “metacognition” by Kitchener (1983); hence, they could meaningfully monitor their own process when solving problems (e.g., making all of their ideas consistent without any conflict). On the other hand, empiricist students tended to simply employ the first level of cognitive processing, called “cognition” by Kitchener; they merely read, memorized, practiced, and computed.

As expected, when asked subjects’ opinions about the most influential determinant for the success of learning science, their responses were almost the same as their views about the responsibilities of students when learning science. Constructivist students tended to emphasize the importance of true conceptual understanding (five of them) and a critical review of their own ideas (two of them), whereas empiricist subjects tended to think that to do more problem-solving practices (four of them) and to listen carefully to what the teacher says in class (two of them) were the most important determinants for the success of learning science.

Students’ responses about whether they really applied the scientific concepts they had learned to other situations raised another significant finding. All of the constructivist students selected tried to actually use science in another (real-life) situation because they believed that science was closely related to everyday life. They had more pragmatic and socially contextualized ideas about learning science and applying scientific knowledge. Empiricist students, on the other hand, tended to complain that science was not related to real life; therefore, most of them (five of them) stated that they did not have the opportunity, nor show willingness, to use science in other situations. Moreover, according to students’ self-reflections, the motivation of learning science for the empiricist subjects came mainly from the pressures related to course grades and examination scores (five of them). These responses are somewhat consistent with their criteria in assessing their understanding. Perhaps, because empiricist students relatively lacked a metacognitive processing ability when learning science, they tended to focus on the learning outcomes rather than on the learning procedures. Consequently, their goal of learning was more oriented to course grades than to real understanding. On the other hand, those constructivist students were mainly motivated by their interest and their desire to understand more (five of them), which implied that they had more appropriate attitudes toward learning science. Kempa and Martin-Diaz (1990a, 1990b) proposed four motivational traits

of learning science held by students: (1) to achieve; (2) to satisfy their curiosity; (3) to fulfill or discharge a duty; and (4) to affiliate and interact with other people, and they labeled these “the achievers,” “the curious,” “the conscientious,” and “the social.” According to the students’ responses in present study, the constructivist subjects tended to be “the curious” learners, whereas the empiricist subjects were likely “the conscientious” learners. Kempa and Martin-Diaz (1990a, 1990b) further showed that “curious” learners exhibited preferences for discovery or autonomy-type instructional activities and doing practical work, whereas “conscientious” learners tended to prefer didactic teaching, supporting the finding presented previously that constructivist subjects preferred constructivist-oriented instructional environments. One constructivist student’s response is also worth reporting; she said that:

Right now, I am not very motivated to learn science since our science classes mainly focus on practicing a lot of tutorial problems. Science is nothing more than solving a set of problems in the classes. If we can have more time to explore some interesting science ideas, I definitely would have much higher motivation to learn science.

It seemed that she lacked high motivation in learning science because the actual class environment opposed her preferences. Or, her perceptions about science conflicted with the way science was presented by her teacher. We can see how a student’s affective responses to learning environments or epistemological orientations toward science influence his or her learning motivation.

Moreover, most students interviewed, regardless of whether they were constructivist or empiricist subjects, viewed the concept of buoyancy to be the most difficult topic they had learned. However, they had quite different strategies for overcoming the difficulty. For example:

R: How did you overcome the difficulties when learning some scientific concepts?

CM5: I would ask classmates first. But, I would try to use own way to understand it. You know, when I ask them, what I learn is their ideas, not mine. I should try to figure them out by myself. Otherwise, I cannot solve the problems by myself if encountering quite different problems.

CF3: In the beginning, I was misled by the idea that I should carefully remember the formulas and intensively practice different types of tutorial problems. As a result, I memorized a lot of formulas but I did not conceptually understand what they meant. Later, I found that there was only one single concept in buoyancy and then I applied this concept to various situations about buoyancy.<sup>4</sup>

CM4: First, I thought that many scientific concepts were very abstract or very static. Later, I felt better when I tried to use a more flexible and creative way to learn science. When I read the textbooks, interpret the graphs, and solve the problems, I imagine that I am actually doing the experiments or in the situations. It is as if all of the experiments and results are concretely presented in front of me. Right now, I think science is something we can imagine or it is very concrete for us to think about it. . . . In this way, I feel it is easier to learn science.

CF6: When learning the concept of air pressure, I found it was very difficult to understand. (R: Could you tell me why?) At that time, because of the cramming schedule, the teacher quickly finished the topic. I could not catch up. (R: How did you overcome such a difficulty?) I asked my classmates. But I thought that, after I slowly went through the whole group of ideas, I could effectively internalize the concepts. I think I really need enough time to understand something.

Again, these constructivist students showed more appropriate views about learning and employed more meaningful approaches when learning science. For example, CM5 shared the belief that learning was a kind of personal interpretation, whereas meaningful learning did not simply come

<sup>4</sup> Similar responses were presented by CM1.

from a copy of others' ideas (e.g., he stated that "When I ask them, what I learn is their ideas, not mine. I should try to figure them out by myself."). For CF3, her epistemological commitment about the consistency of scientific knowledge encouraged her to use a single concept to solve various problems about buoyancy. CM4 appreciated that science was concrete and he tried to use imagination when understanding some scientific concepts that were likely abstract. For CF6, learning science was a time-consuming knowledge construction, and she hoped to have more time when constructing the scientific ideas. Only one constructivist student responded that she did more problem-solving practice problems to overcome the learning difficulty. However, this method was commonly used among empiricist students. For example:

R: How did you overcome the difficulties when learning some scientific concepts?

EM2: I would try to follow the solutions provided by textbooks or reference books. After a lot of practices, I found I gradually understood the concept.

EF4: I tried to list all of the formulas and tried to clarify the relationships between them. Then, I did more problem-solving practices to become familiar with these formulae.

EF1: I asked classmates first. But I think doing more practices is also important in overcoming the difficulty.

EM2 held the view, likely opposite to CM5, that we could learn science by copying others' ideas; hence, he tried to follow the solutions by textbooks or reference books to enhance his learning. Moreover, most empiricist students tended to believe that intensive practices could improve the understanding of some scientific knowledge. Again, this learning belief may be reinforced by their empiricist epistemology that science is a collection of correct facts; therefore, intense practices can help people get acquainted with these truths. Although one student (EF1) mentioned the importance of discussion with others, she still stressed the usefulness of practices. Finally, students' ideas about what a successful science teacher should be like were explored:

R: In your view, what is the most successful science teacher like?

CF6: He [or she] should just point out the big ideas and then focus on their applications on our real life. Also, he [or she] should understand every student's ability in learning science and then give special instruction to those in need. He [or she] should teach science at a slower rate so we can figure out our ideas in classes. And then if something is unclear, we can ask immediately. Don't try to cram a lot of ideas into a very short period of time.

CM4: He [or she] should know that the purpose of instruction is to teach some basic concepts, not the most difficult problems. In fact, those difficult problems are based on the basic concepts. The teacher should be willing to discuss topics with students. Students can ask questions without the fear of making mistakes.

MM5: He [or she] should have enough background knowledge in science. He [or she] should discover students' difficulties in learning some scientific concepts. We had common barriers in learning some scientific concepts. At a certain point, we cannot figure them out. He [or she] should notice this; he cannot just tell all of us perfectly correct answers. Also, he [or she] should emphasize true understanding, not just the grade or exam score.

Constructivist students tended to prefer learning the depth, not the breadth, of scientific knowledge (e.g., the big ideas and the basic ideas). Again, they highlighted the need for enough time to construct knowledge and the importance of discussion without the fear of making mistakes. It was also impressive that one mixed epistemology student (MM5) had a pedagogical view close to the "alternative conception" proposed by science educators (Wandersee, Mintz, & Novak, 1994). He believed that a successful science teacher should pay attention to students' alternative conceptions

when teaching science. On the other hand, empiricist students tended to view that a clarification of the correct scientific facts was important for a successful science teacher. For example:

R: In your view, what is the most successful science teacher like?

EM2: He [or she] can make every student learn the correct concepts.

EM5: He [or she] should explain all of the concepts for every detail, without missing any words. He [or she] should give us more opportunities to do more problem-solving practices.

EF1: He [or she] should teach the scientific knowledge presented in the textbook very clearly. But, to be honest, we frequently do not really try to learn in classes. We often try to “digest” some concepts long after the teacher taught them. Hence, I think that a successful science teacher should assign a lot of after-class work for us to do and strictly ask us to finish. This can push us to learn effectively.

EF1’s forgoing responses raised another implication for this study. She exemplified the following: Possibly because empiricists believe that science is a fixed body of infallible facts or received knowledge, they assume that we can learn science at any point. That is, science is interpreted as some static information already existing there for them to learn; hence, it is not necessary for them to try to construct their ideas right in class. They can, if they want, directly transfer these facts from outside into their mind. This epistemological orientation could somewhat explain the finding revealed by Tsai’s (in press) study that empiricist subjects tended to have lower cognitive structure outcomes than constructivist subjects in an immediate recall test of learning basic atomic theory.

In conclusion, this study revealed some interactions between students’ SEB and learning orientations. Students having SEB closer to constructivist views tended to learn through constructivist-oriented instructional activities such as interacting with others’ ideas, and meaningfully controlling their learning activities. This finding, implying that an appropriate view about the constructivist philosophy of science is an essential prerequisite for implementing constructivist science teaching, could be fundamentally important for numerous current science educators advocating the practice of constructivism for science education (e.g., Tobin, 1993; Treagust, Duit, & Fraser, 1996). Moreover, as observed by Edmondson (1989) and Hammer (1995), constructivist-oriented students tended to employ a more active manner and use more meaningful strategies when learning science or assessing their understanding, whereas students holding empiricist SEB tended to have a passive mode of learning and use more rote-like strategies to enhance their learning. Constructivist students focused on the depth of the scientific concepts and they hoped to have enough time to understand some basic concepts. Constructivist students tended to apply science to other situations, indicating a pragmatic view of using school science; moreover, they were mainly motivated by their interest and aspiration to know more. However, empiricist students tended to hold the view that science did not have application in real life, and they were mainly motivated by course grade or examination pressure.

It could also be concluded that, although the subjects in this study were those educated in Eastern cultures, the interplay between students’ SEB and their learning orientations was similar to that revealed in Western countries (e.g., Edmondson, 1989). This study further suggests that such an interplay may exist for younger learners. It implies that we, as science educators, must appropriately shape the image of science for students, especially from an early age.

## IMPLICATIONS

Although this study was not conducted using an experimental research design, the results support findings by earlier research (e.g., Edmondson, 1989; Hammer, 1995), and strongly suggest that students’ SEB play a significant role in students’ learning orientations and how they organize

scientific information. Recent research further implies that students' epistemological views may mainly come from their formal education (Gallagher, 1991; Tsai, 1996b). Unfortunately, research on the analyses of science curriculum programs, content of textbooks, teachers' epistemological beliefs, and classroom instructional strategies repeatedly shows that science education is conducted in the context of empiricist epistemological traditions (Abimbola, 1983; Duschl, 1988). Consequently, we are facing two apparent dangers: one is a pedagogical danger that teaching science becomes a business of rote memorization of standard facts, laws, theories, methods, and problem-solving procedures; and the other is an epistemological danger that science is viewed as infallible knowledge and a body of absolute facts or received knowledge (Millar, 1989).

The following solutions may help us to avoid these dangers. First, many educators have highlighted that science teachers should have more appropriate intellectual knowledge about the philosophy of science (e.g., Beson, 1989; King, 1991); however, they are not encouraged to enroll in courses about the philosophy of science as part of their academic study (Gallagher, 1991). Teacher education programs should offer relevant courses to help students acquire an adequate understanding of the (constructivist) philosophy of science. We can offer interdisciplinary courses about the history, sociology, and philosophy of science (Pitt, 1990) or present scientists' arguments in the historical context to illustrate the philosophy of science (King, 1991). The article by Summers (1982) provides a concise review of contemporary resources and a set of curriculum guidelines about the philosophy of science for science teacher education programs.

Second, our science curriculum should focus not only on scientific knowledge (learning science) but also on knowledge about science (learning about science) (Duschl, Hamilton, & Grandy, 1990). Students should learn not only what is known by science, but also how science comes to achieve such knowledge. The science curriculum should explicitly address the goals of science and the development of scientific knowledge; that is, teaching the scientific metaknowledge (Reif & Larkin, 1991). The science–technology–society trend proposed by current science educators can be viewed as another attempt to deeply explore the epistemology of science for students (Bybee et al., 1991). Science does not arise from a vacuum; rather, it comes from a complex interaction between social, technological, and scientific development. Certainly, the growth of science results in another complicated interaction between science, technology, and society.

Finally, the way we teach can also play a role on the development of students' epistemological views about science. The study completed by Lederman and Druger (1985) shows us that frequent inquiry-oriented questioning, continual uses of anecdotes, and a supportive classroom atmosphere can help students have a better understanding about the (constructivist) nature of science. Creating a learning environment where students have opportunities to negotiate, to challenge, and to question their own ideas, others' ideas, or even the teacher's ideas, can promote their epistemological understanding about science. We should, either explicitly or implicitly, make epistemological perceptions as part of routine instructional awareness (Hammer, 1995). Altogether, students can have a better understanding of the constructivist philosophy of science. Moreover, it follows that they are expected to have more meaningful orientations as well as more appropriate attitudes toward learning science.

## APPENDIX: INTERVIEW QUESTIONS EXPLORED IN THIS STUDY

### (a) *Scientific epistemological views:*

1. If someone asks you "what is science?," what will you tell him or her?
2. What are the main characteristics of scientific knowledge?
3. What are the differences of scientific knowledge and other knowledge?
4. Where do scientists get their ideas?
5. What kind of ideas do scientists have?

6. Do scientists do anything with their ideas? What and how do they do with them?
7. Some astrophysicists believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?
8. After scientists have developed a theory, does the theory ever change? Why (when, how) or why not?

(b) *Beliefs about learning and learning science:*

1. Describe (or imagine) a classroom situation where you felt (or feel) as though you were (or are) really learning?
2. What do you think your responsibilities are as a student?
3. How do you ensure that you have already known something? For example, when you learn the concept about density, how do you ensure that you have already understood the concept of density?
4. What is the most important determinant for the success of learning science? Why?
5. Have you ever tried to use the scientific concepts you have learned in other situations? How?
6. What do you think motivates you to learn science?
7. What was (or were) the most difficult topic(s) when you learned science? How? Why? How did you overcome the difficulties?
8. In your view, what is the most successful science teacher like? Why?

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