

# “Laboratory Exercises Help Me Memorize the Scientific Truths”: A Study of Eighth Graders’ Scientific Epistemological Views and Learning in Laboratory Activities

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*Received 15 December 1997; revised 25 September 1998; accepted 1 October 1998*

**ABSTRACT:** Upon analysis of 25 Taiwanese eighth graders’ questionnaire responses, actual laboratory observation recording, and interview details, the present study was conducted to explore the interplay between students’ scientific epistemological views (SEVs) and their learning in school laboratory activities. It was revealed that, although higher achievers tended to have a greater frequency of verbal negotiations directly related to laboratory details, students’ SEVs were also related to their laboratory verbal interactions. It was found that students having SEVs more oriented to constructivist views of science, called constructivist students, tended to focus more on negotiating the meanings of experiments with their peers than did students having SEVs more in line with empiricist views of science, called empiricist students ( $p < 0.05$ ). Constructivist students perceived actual laboratory learning environments as less open-ended and less integrated ( $p < 0.05$ ) and they tended to prefer a more student-supported and open-ended approach to experimentation ( $p < 0.05$ ). Interview details showed that constructivist learners tended to explore deeply the involved concepts of laboratory activities, resulting in a richer understanding. On the other hand, empiricist learners placed greater emphasis on “doing” laboratory work, following the codified procedures of science textbooks, and they believed that laboratory exercises made scientific concepts more impressive, acting as memory aids. This study concludes that an appropriate understanding of the constructivist epistemology of science should be an essential prerequisite for implementing so-called “constructivist science teaching.” © 1999 John Wiley & Sons, Inc. *Sci Ed* **83**:654–674, 1999.

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Contract grant sponsor: National Science Council, Taiwan, ROC; contract grant number: NSC86-2511-S009-010-T

## INTRODUCTION

In the past two decades, science education researchers have extensively investigated students' "misconceptions" or "alternative conceptions" in various scientific domains (e.g., Driver & Easley, 1978; Novak, 1987; Wandersee, Mintzes, & Novak, 1994). A plethora of research literature has shown that students' alternative conceptions greatly influence subsequent learning. Recently, many science educators have emphasized the importance of the philosophy of science for science education (e.g., Duschl, 1985, 1990; Hodson, 1985, 1988, 1991). It is plausible to expect that students' personal philosophy of science, which could be viewed as "alternative scientific epistemological views," may also influence their science learning. Available research evidence has shown that students' *scientific epistemological views* (SEVs) play an essential role in determining their learning orientations toward science (Edmondson, 1989; Hammer, 1995; Songer & Linn, 1991; Tsai, 1998a). Science educators have identified an individual's SEVs as an important feature of his or her conceptual ecology (Demastes, Good, & Peebles, 1995; Posner, Strike, Hewson, & Gertzog, 1982). Students' SEVs have been related to the extent, richness, and precision of their cognitive structure outcomes of science learning (Tsai, 1998b) and to level of performance on learning tasks requiring abstract problem solving (Novak, 1988).

Educators suggest that epistemological orientation is a higher order belief that guides learning or cognitive processes (Hofer & Pintrich, 1997; Tsai, 1996a). In a similar manner, it is likely that students' SEVs will shape their metalearning assumptions when learning science. For example, if students' perceive science as a collection of proven facts, they will focus on memorizing these truths and will attempt to prove them through codified procedures provided by the scientific method. On the other hand, if learners view science as a constructive process of concept development and meaning negotiation, they will emphasize concepts and their variations (Roth & Roychoudhury, 1994). Likewise, their SEVs may be also related to their learning strategies in laboratory activities; however, there has been no prior study addressing this issue.

This study was conducted mainly based on the following three rationales. First, many educators repeatedly highlight that laboratory exercises represent the most appropriate way of exploring the methods and the nature of science for students (e.g., Blosser, 1990; Layton, 1990; Lazarowitz & Tamir, 1994). As proposed previously, students' SEVs, representing their perceptions of science, potentially affect how they conduct laboratory activities, how they perceive laboratory instruction, and consequently how they interact with others in laboratory activities. However, the interplay between students' SEVs and their learning in laboratory activities remains unexplored in science education literature. Second, Johnson and Johnson (1989) have emphasized the importance of studying student–student interactions in science classrooms. Many agree that students' laboratory environments are proper places to study student–student social interactions (e.g., Solomon, 1989). This study is an attempt to explore this issue further. Third, the findings derived from this study may also be important for current science education practice, advocating so-called "constructivist science teaching." In the framework of constructivism, science educators have suggested the use of inquiry, questioning, and open-ended instructional strategies, and they further assert that meaningful learning and knowledge construction should come from students' social negotiations and interactions (e.g., Taylor & Fraser, 1991; Tsai, 1998c).<sup>1</sup>

<sup>1</sup> However, "constructivist science teaching" also highlights the key role played by the teacher in introducing the scientific viewpoint (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Also, although constructivism is still a controversial topic in science education (Matthews, 1994; Osborne, 1996; Phillips, 1995), the position of this article, as that suggested by Staver (1998) and Tobin (1993), asserts that constructivism is a sound theory to help science educators understand how students learn science as well as to explicate the practice of science and science teaching.

It is clear that all of these instructional orientations correspond to the characteristics of laboratory activities.<sup>2</sup> Recent research has indicated that some students resist adapting to constructivist learning environments in science courses (e.g., Roth, 1997). Students' SEVs may, to a certain extent, influence the usefulness of constructivist-oriented learning activities and then affect their instructional outcomes. This study, an attempt to analyze the interplay between students' SEVs and their learning in laboratory activities, could be viewed as a research foundation of how these SEVs may influence the practice of constructivism in science classrooms. Through analysis of actual laboratory observations, questionnaire responses, and interview details, this study seeks to answer the following research questions:

1. To what extent, and in what way, are there relationships between students' SEVs and their social verbal interactions in laboratory learning activities?
2. To what extent, and in what way, are there relationships between students' SEVs and their perceptions about actual and preferred laboratory learning environments?
3. How do student interview results substantiate quantitative findings and then help us interpret the interplay between students' SEVs and their views about the nature and the aims, values, and other relevant beliefs of laboratory activities?

Prior relevant research (e.g., Edmondson, 1989; Tsai, 1997, 1998a) revealed that, when compared to students holding the belief that science was discovered from absolutely objective observation and experimentation (i.e., empiricist-oriented SEV), students who believed that scientific knowledge was constructed on the basis of scientists' agreed-upon paradigm, evidence, and negotiation (i.e., constructivist-oriented SEV) tended to:

1. Employ more meaningful strategies when learning science.
2. Have better attitudes and more appropriate learning beliefs toward school science.
3. Show stronger preferences for constructivist-oriented instructional environments.

Based on these available findings, this study predicts that constructivist-oriented SEV students will have more social interactions with their peers during the conducting of laboratory activities than empiricist-oriented SEV students. Moreover, students having SEVs more oriented to constructivist views of science will show greater preference for a highly peer-supported and open-ended laboratory environment. In addition, they will perceive the purposes of the school laboratory in a more appropriate way than empiricist SEV learners.

## METHODOLOGY

### Subjects

This research was conducted with a selected group of eighth grade students (13–14-year-olds) from two classes in a junior high school in Hsinchu, Taiwan. The two classes, a total of 86 students, were taught by the same science teacher. To strengthen the validity of this study, students who expressed a strong certainty or confidence about their SEVs based on questionnaire responses (Pomeroy's questionnaire, 1993, described later) were selected. This criterion was employed because the students were expected to be highly

<sup>2</sup> It is realized that many school laboratory activities involve performing routine and standard tests. However, when compared to other instructional methods commonly used (e.g., lecturing, textbook reading), laboratory experiences may possibly provide more opportunities for both teachers and students to conduct open-ended instructional activities and to engage in social interactions.

aware of their epistemological orientations toward science, an important variable considered in this study. Among those who met the aforementioned criterion, a total of 28 students from the participating classes were randomly chosen for this study. However, three of the selected subjects were unexpectedly absent from some laboratory observation sessions during the process of conducting this study; therefore, the final sample consisted of 25 eighth graders (12 girls and 13 boys).

### Instrument Assessing Subjects' SEVs

Three weeks before actually observing students' social interactions in laboratory activities, a Chinese version of Pomeroy's questionnaire (1993) was administered to assess students' SEVs. 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, suggesting a static perspective about the nature of science, tend to support that: (1) scientific knowledge is unproblematic and it provides the *right* answers; (2) scientific knowledge is *discovered* by the *objective* data gathered from observing and experimenting or from a universal scientific method; and (3) scientific knowledge is additive and bottom up, and evidence accumulated carefully will establish infallible knowledge (Carr et al., 1994; McComas, 1996; Strike & Posner, 1985). On the other hand, the constructivist views, which claim the dynamic nature of science, assert that: (1) observations or experimentation in science is theory-laden; (2) based on agreed-upon paradigm and evidence, scientific knowledge is cooperatively *constructed* or *invented* by the negotiations among scientists; and (3) scientific development experiences a series of paradigm shifts (Kuhn, 1970; Tsai, 1998c). The questionnaire for this study was developed by selecting Pomeroy's items representing “traditional views of science” (empiricist views; e.g., scientists rigorously attempt to eliminate human perspective from observation) and “non-traditional views of science” (constructivist views; e.g., nonsequential thinking, i.e., taking conceptual leaps, is characteristic of many scientists). The questionnaire included a total of 17 items. Pomeroy (1993) reported that the internal consistency for these two parts of the questions was moderately high (Cronbach's  $\alpha = 0.651$ , and  $0.591$ , respectively).

To assess respondents' certainty or confidence about their SEVs, after making a choice of each question, they were asked to answer the following: “Concerning this choice, I am: (1) guessing, (2) uncertain, (3) fairly certain, or (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 the items identified as *confident* were viewed as appropriate subjects for this study. The translation of Pomeroy's questionnaire (1993) was validated by two Chinese-speaking researchers and the Chinese version questionnaire showed adequate internal consistency in Tsai's (1996b) study.<sup>3</sup> In addition, further evidence of the questionnaire's validity was obtained by interviewing 20 students from Tsai's (1998a) study, and it was concluded that their SEVs, as deduced from interview questions, were generally consistent with their responses on the questionnaire.

Students' responses of *confident* items on Pomeroy's questionnaire (i.e., showing students' strong certainty or confidence) were scored as follows. For the “constructivist-perspective” items, a “strongly agree” response was assigned a score of 5 and a “strongly

<sup>3</sup> Because there were missing data for students' questionnaire responses (i.e., those without students' confidence), Tsai's (1996b) study could not properly conduct  $\alpha$  reliability testing to assess the questionnaire's internal consistency. Tsai's study finally used the correlation coefficients between the student's response on every individual item and his or her average score on all of confident items to assess the consistency of this questionnaire. Except for one question, the correlation coefficients (ranging from 0.43 to 0.67) were significant at the 0.05 level. The present study excluded the question, resulting in a total of 16 questions for analyses.

disagree” response was assigned a score of 1. Items representing an empiricist view were scored in a reverse manner. 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’ SEVs; namely, a continuum from empiricist to constructivist perspectives.

### Recording Subjects’ Laboratory Social Interactions

Subjects’ social interactions in laboratory activities were actually observed by eight trained researchers. Every researcher observed one or two subject(s) at the same time. If one researcher observed two subjects at the same time, these two subjects were those originally in the same laboratory group. The researchers did not acquire any relevant information about the observed subject(s) (e.g., the student’s SEV or science achievement) when making laboratory recordings. Also, the researchers did not intentionally reveal who the final subjects were during the process of conducting observations. Observation data were collected from six laboratory sessions in each of both classes observed (about 50 minutes for each session). The length of observation time in these two classes was the same, so was the content of observed laboratory activities, including some experiments about chemical reactions, acid and base, static equilibrium, and Newton’s laws of motion. These laboratory activities were those normally conducted by Taiwanese eighth graders, not designed intentionally for these two classes. The laboratory approach in these observation sessions was oriented in a traditional manner (e.g., textbooks provided fixed experimental procedures), the same as that in common Taiwanese science classes. The observed laboratory activities in these two classes were guided by the same science teacher (their original teacher). Students in each class were divided into seven small groups. Each group included five to seven students of both genders and varying levels of academic achievement. In order to enhance the objectivity of research data, the researchers changed their subject(s) of observation every session; that is, each subject’s social interactions were recorded by different researchers over different sessions. The researchers did not socially interact with students during the observation sessions, and they did not participate in the instructional design nor conduct any laboratory teaching.

In order to acquire a better description of students’ social interactions, this study did not employ interval observation methodology (e.g., every 30 seconds record an observation); instead, the observation recording unit was based on *each* segment of the subject’s discourse that expressed a complete purpose or discussion, or responded to one questioning prompt (e.g., “Could I use the bottle?” or “The experimental outcomes seem to confirm the Newton’s second law of motion because the larger the force, the greater the acceleration”). Because this study attempts to further classify the content of students’ discourse negotiations (described later), this way of recording could not only include all student negotiations as research foundation, but also focus more on students’ ideational expressions involved in their interaction sequences. As a result, the social interactions explored by this study were limited to *verbal* interactions. This way of documenting students’ social interactions was similar to that done by Keys (1996), who observed ninth graders’ negotiations in writing collaborative laboratory reports. In the present study, every discourse segment was analyzed based on the following five major negotiation categories, which were obtained primarily from Shepardson (1996): negotiation of status; negotiation of action; negotiation of meaning; negotiation of material; and other. These are explained more fully as follows:

1. *Negotiation of status.* A verbal interaction sequence between actors (including the teacher and student[s]) that grants privilege or authority to one actor over other

- actors during laboratory activities. For example: “You have to let me do that first” and “You could use the instrument before her.”
2. *Negotiation of action.* A verbal interaction sequence between actors, whereby one actor’s interaction elicits an action by one or more actors during laboratory activities. For example: writing or drawing experimental results or making or recording experimental observations (e.g., “We have to record the data here,” “Write the results into the table,” “You should carefully observe the color of the material”).
  3. *Negotiation of meaning.* A verbal interaction sequence between actors whereby one actor’s interaction results in a sharing or communication of understanding of the science phenomena by one or more actors during laboratory activities. For example: explaining or describing the experimental results of the Newton’s second law of motion (e.g., “The result shows that this variable is related to that variable,” “What does the result mean?” “The results confirm Newton’s second law of motion”).
  4. *Negotiation of materials.* A verbal interaction between actors wherein one actor’s interaction results in a sharing or distribution of materials by one or more actors during laboratory activities. For example: the use of experimental instruments (e.g., “Could you borrow me a pipette?” “Distribute the samples to everyone”) and also statements like “How many grams of HCl do we need for this experiment?” were classified in this category.
  5. *Other.* Verbal interaction sequences between actors that do not fit the aforementioned category definitions. Usually, the content of these sequences is not related to laboratory activities. For example: Today is James’s birthday. I bought a toy yesterday.

The verbal interaction sequences recorded in this study included student–student and student–teacher interactions. Actually, after examining the observation recordings, 97% of the interactions found were student–student negotiations. The science teacher, as is common in science classes, did not frequently interact with students. Before conducting the present study, the eight researchers involved were trained and asked to actually do some laboratory observations based on the coding system. Also, the first observation session in each class was excluded for final analyses to enhance the validity of the research data, as these researchers may not have been very skilled at such observation activities in the first session. Such practices also helped researchers to clarify some uncertain categorizations. As a result, there were five total sessions from each class that were finally included in the research investigation. To further assess the validity of the observation results, three randomly selected participating researchers were asked to analyze two subjects’ videotaped recordings. It was found that the average agreement among these researchers was 0.87, by employing the aforementioned coding system. Moreover, all participating researchers together discussed some ambiguous classifications of students’ discourse segments after each observation session. Students’ verbal interactions that did not receive researchers’ consensus (<1% of total interactions observed) were not included in the final analyses.

### **Instrument Exploring Subjects’ Perceptions of Laboratory Activities**

The Science Laboratory Environment Inventory (SLEI), developed and validated by Fraser, Giddings, and McRobbie (1995), was administered to explore subjects’ perceptions of laboratory activities. SLEI has two forms: one is the (personal) actual form, which investigates students’ views about actual laboratory environments; and the other is the (personal) preferred form, which assesses students’ perceptions about ideal laboratory environ-



ments. Each (personal) form includes the following five different scales, and each scale consists of seven questions:

1. *Student Cohesiveness Scale*. The extent to which students know, help, and are supportive of one another. Example: I am able to depend on other students for help during laboratory classes (actual form), or I would be able to depend on other students for help during laboratory classes (preferred form).
2. *Open-Endedness Scale*. The extent to which the laboratory activities emphasize an open-ended, divergent approach to experimentation. Example: In my laboratory sessions, I do different experiments than some of the other students (actual form).
3. *Integration Scale*. The extent to which the laboratory activities are integrated with nonlaboratory and theory classes. Example: The laboratory work would be unrelated to the topics that I am studying in my science class (preferred form, stated in a reverse manner).
4. *Rule Clarity Scale*. The extent to which behavior in the laboratory is guided by formal rules. Example: My laboratory class has clear rules to guide my activities (actual form).
5. *Material Environment Scale*. The extent to which the laboratory equipment and materials are adequate. Example: I would find that the laboratory is crowded when I am doing experiments (preferred form, stated in a reverse manner).

Students' responses on the SLEI were scored as follows. For the positively stated items, a "very often" response was assigned a score of 5 and an "almost never" response was assigned a score of 1. Items stated in a reverse manner were scored in a reverse manner. Therefore, students perceiving or preferring their laboratory environments as student-cohesive, open-ended, integrated with theory classes, and had clear rules as well as adequate materials would have higher total scores on the responding scale (full score on each scale = 35).

Fraser et al. (1995) reported that the reliability coefficients (Cronbach's  $\alpha$ ) of the SLEI were 0.78, 0.71, 0.86, 0.74, and 0.76 on each scale for the actual form, whereas the coefficients were 0.73, 0.70, 0.84, 0.68, and 0.73 on each scale for the preferred form. The translation of SLEI was validated by two Chinese-speaking researchers. A pilot study, administering the Chinese version of the SLEI to 113 eighth graders from the study site (but not the study subjects), showed that its reliability coefficients were 0.80, 0.79, 0.83, 0.68, and 0.70 on each scale for the actual form, whereas the coefficients were 0.85, 0.80, 0.75, 0.71, and 0.73 on each scale for the preferred form, indicating that the Chinese version of the SLEI, both actual and preferred forms, has adequate internal consistency in assessing students' perceptions of laboratory environments. These two forms of the SLEI were administered separately to all of the students in these two classes (not only the final subjects) during approximately the midpoint of the present study.

## Student Interviews

In order to acquire a better understanding of the interplay between students' SEVs and their perceptions, as well as learning orientations of school laboratory activities, *all* of the final subjects involved in this study were interviewed. The qualitative details were used not only to validate the quantitative results, but also to provide some plausible interpretations for the findings drawn from this study. Two weeks after completing all of the students' laboratory observations, the interviews were conducted individually by two trained researchers (each interviewed half of the subjects). The interview questions con-

sisted of two major parts: one exploring students' SEVs and the other researching their perceptions and learning orientations in school laboratory activities. The first part employed mainly the interview questions from Tsai's (1998a) study, addressing students' views about science, the sources of scientists' ideas, the possible changes of scientific knowledge, and the purposes of the scientists' experiments. The second part included basically the following interview questions:

1. Why do science classes need laboratory exercises?
2. Describe (or imagine) an ideal laboratory learning environment where you felt (or feel) as though you were (or are) really learning?
3. How do your school laboratory activities help you understand something (if any)?
4. In the laboratory activities, how do you manage your time on these activities?
5. What role do you play in laboratory activities? What do you prefer to play?

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 Chinese speaker, 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 each subject's particular SEV position, as assessed by Pomeroy's questionnaire (1993).

## RESULTS AND DISCUSSION

### Background Variables (Science Achievement and Gender) Exploration

In the first part of the analysis, subjects' science achievement and gender were viewed as possible covariates that might be related to their social (verbal) interactions in laboratory activities and their perceptions about laboratory learning environments. Students' science achievement was represented by their scores on three school-wide science tests. These examinations were implemented during the conducting of this study. Furthermore, this study totaled subjects' results, which were classified as negotiation of status, action, meaning, and material into a new variable, called "valid" negotiation, representing subjects' verbal interactions that were directly related to laboratory activities. Table 1 shows the correlation between students' science achievement and observed laboratory verbal negotiations.

Students' science achievement was not significantly correlated with their verbal negotiations of status, action, meaning, and material in observed laboratory sessions (all  $p$ -values nonsignificant at the 0.05 level); however, students' science achievement was significantly related to students' "valid" verbal negotiations ( $r = 0.40$ ,  $p < 0.05$ ). That is, higher achievers tended to have more verbal interactions directly related to laboratory

**TABLE 1**  
Correlation between Students' Science Achievement and Verbal Negotiations in Laboratory Activities ( $n = 25$ )

	Status	Action	Meaning	Material	Other	Valid
Science Achievement	0.23	0.34	0.26	0.35	-0.02	0.40 <sup>a</sup>

<sup>a</sup> $p < 0.05$ .



**TABLE 2**  
**Correlation between Students' SEVs and Verbal Negotiations in Laboratory Activities ( $n = 25$ )**

	Status	Action	Meaning	Material	Other	Valid
SEVs	0.03	0.12	0.44 <sup>a</sup>	-0.02	-0.14	0.27

<sup>a</sup> $p < 0.05$ .

activities, but they did not show strong preferences on particular negotiation categories defined in this study. It is plausible that the more well-developed schemata possessed by higher achievers may have facilitated their frequent use of negotiations of laboratory details with peers.

Moreover, students' science achievement was not significantly correlated with students' perceptions of actual and preferred laboratory environments, as assessed by the SLEI instrument.<sup>4</sup> Also, gender in this study was not statistically related to students' verbal negotiation recording and perceptions of laboratory environments at the 0.05 significance level. In summary, students' science achievement and gender generally may not have been important covariates when exploring the relationships between students' SEVs and their learning or perceptions of school laboratory work.

### Relationship between Students' SEV and Laboratory Verbal Negotiations

The relationship between students' SEVs and their laboratory verbal negotiations is shown in Table 2. Students' SEV dimension did not correlate with their verbal negotiations of status, action, material, and other, nor did it correlate with valid interactions upon summation of those directly related to laboratory activities (all nonsignificant at the 0.05 level). As concluded previously, students' science achievement was a significant covariate of their valid negotiations (shown in Table 1); therefore, when exploring the relationship between students' SEVs and their valid verbal interactions, their achievement must be controlled for. A further analysis revealed that the partial correlation between subjects' SEVs and valid negotiations was 0.34 (nonsignificant, as shown in Table 3). Students' SEVs did not have a statistical impact on their "valid" verbal interactions in observed laboratory activities, even after controlling for their science achievement.

However, there was a positively significant correlation between students' SEV and their

**TABLE 3**  
**Partial Correlation between Students' SEVs and Verbal Negotiations in Laboratory Activities, Controlling for Science Achievement ( $n = 25$ )**

	Status	Action	Meaning	Material	Other	Valid
SEVs	0.06	0.17	0.49 <sup>a</sup>	0.02	-0.14	0.34

<sup>a</sup> $p < 0.05$ .

<sup>4</sup> Another correlation coefficient may be worth reporting that students' science achievement was not statistically related to their SEV scores ( $r = -0.10$ , not significant).

negotiations of meaning in their laboratory discourse ( $r = 0.44, p < 0.05$ ; see Table 2). When controlling for science achievement, such a correlation became more obvious ( $r = 0.49, p < 0.05$ ; see Table 3); that is, students having SEVs more oriented to constructivist views of science tended to negotiate the involved meanings of laboratory activities with their peers (or teacher) more frequently than those holding empirically aligned SEVs. This relationship is further illustrated in Figure 1. Figure 1 divides the subjects into three groups: (1) the constructivist group, students scoring in the top third of their SEVs (a total of eight subjects, called “constructivist students”), those having constructivist-oriented SEV; (2) the empiricist group, students scoring in the bottom third of their SEVs (a total of eight subjects, called “empiricist students”), those holding empiricist-aligned SEVs; and (3) the mixed group, students scoring in the near-average area of their SEVs (i.e., the rest of the subjects, a total of nine, called “mixed students”), those holding neutral beliefs supporting both constructivist and empiricist SEVs or a mix of both views.

According to Figure 1, students in each group tended to have more frequent verbal interactions in the categories of negotiations of meaning and action, which were more relevant to the content of laboratory activities. This finding somewhat contradicts the conclusion drawn from Shepardson’s (1996) study that “children’s small-group social interactions did not result in a negotiation of meaning” (p. 173). However, it should be noted that the subjects in Shepardson’s study were first graders, whereas those in the present study were eighth graders who had developed conceptually richer schemata and could better negotiate meaning with others.

Moreover, Figure 1 reveals that constructivist students tended to have significantly more frequent negotiations of meaning in the observed laboratory sessions, as compared with the other groups of students, the same as the correlation analysis in Table 2 and Table 3. The group differences in other negotiation categories were not apparent. This finding can

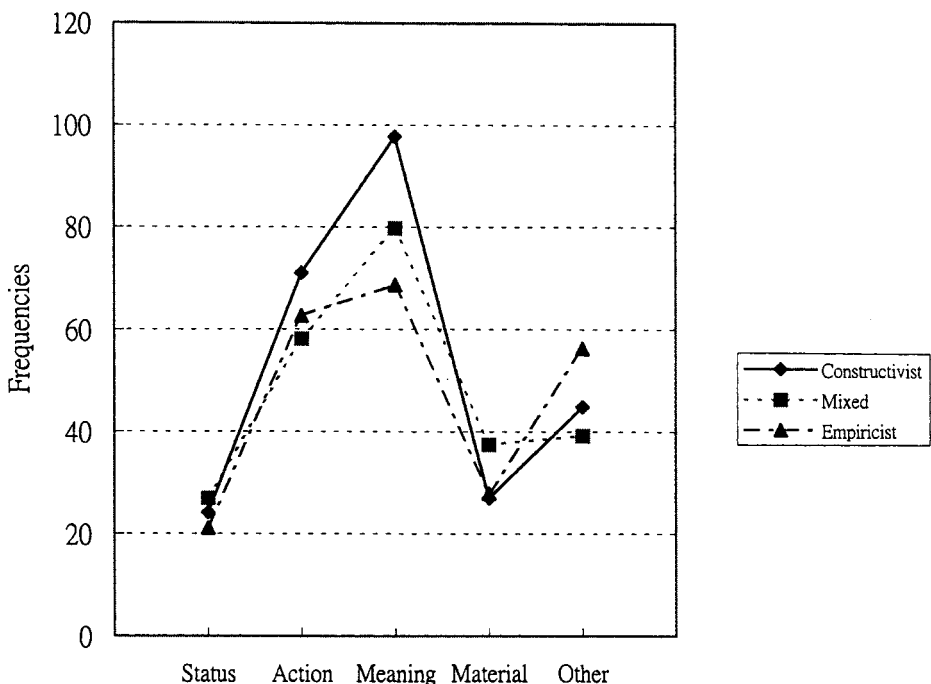


Figure 1. Laboratory verbal interactions by different SEV group subjects.

also be examined in the following way: Constructivist students had 44.5% of their valid negotiations in the “meaning” category, whereas mixed and empiricist learners had 39.4% and 38.1% of valid negotiations on that category. Or, 36.9% of total negotiations (including all of the five categories) shown by constructivist subjects were classified in the “meaning” category, whereas only 33.0% and 29.0% of total negotiations held by mixed and empiricist learners, respectively, were recorded in the same category. Relatively speaking, constructivist students put more effort into interpreting or explaining the experimental outcomes (almost a half of their valid negotiations), whereas the other two groups did not show such a clear tendency. For example, empiricist students had a similar frequency of negotiation in “action,” “meaning,” and “other” categories. This implies that constructivist learners tended to explore in greater detail the involved concepts of laboratory activities.

The beliefs that scientific knowledge comes from people’s negotiations and that science is cooperatively developed by meaning construction of the science community may have induced constructivist subjects to negotiate the meanings of experimental results with their peers or teacher. They paid more attention to describing and explaining the experimental outcomes and then to reaching a shared understanding among laboratory partners. On the other hand, if students held empiricist SEVs, asserting that science is a collection of proven facts, they would not view negotiations of meaning to be essential or necessary in laboratory exercises, because, for them, science does not allow other possibilities and debates. Consequently, empiricist (group) students may have focused rather on communicating whether the experimental material or other issues (e.g., the status) were correct or appropriate. This finding is consistent with that revealed in Tsai’s (1996b) study, which showed that constructivist students actually tend to learn through negotiations with others. It also somewhat concurs with the conclusion drawn from Tsai’s (1997) later study that constructivist subjects tended to show significantly stronger preferences to learn in environments where they could interact and negotiate meanings with others, compared with empiricist students ( $p < 0.05$ ).

### Relationship between Students’ SEVs and Perceptions of Actual Laboratory Learning Environments

In this subsection, the relationship between students’ SEVs, as assessed by Pomeroy’s (1993) questionnaire, and their perceptions of actual laboratory environments, surveyed via the SLEI actual form, was investigated. Table 4 shows that students’ SEVs were not significantly correlated with their perceptions on the student cohesiveness, rule clarity, and material environment scales of SLEI actual form. However, students having SEVs more oriented to constructivist views about science tended to perceive actual laboratory learning

**TABLE 4**  
**Correlation between Students’ SEVs and Perceptions of Actual Laboratory Environments ( $n = 25$ )**

	SC (Actual)	OE (Actual)	Int (Actual)	RC (Actual)	ME (Actual)
SEVs	-0.27	-0.44 <sup>a</sup>	-0.41 <sup>a</sup>	-0.20	0.26

SC, Student-Cohesiveness scale; OE, Open-Endedness scale; Int, Integration scale; RC, Rule Clarity scale; ME, Material Environment scale.

<sup>a</sup> $p < 0.05$ .

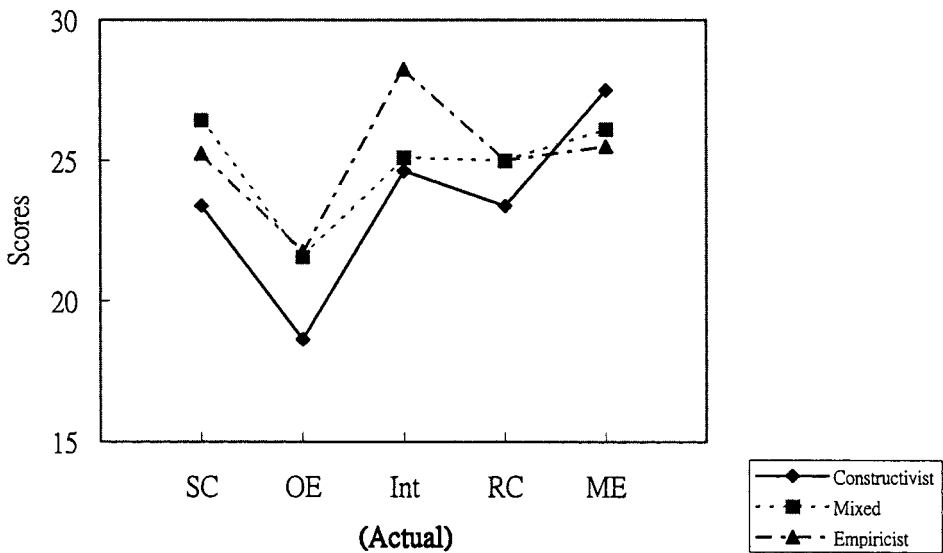


Figure 2. Students' perceptions of actual laboratory learning environments by different SEV group subjects.

environments as less open-ended and less integrated than those holding SEVs more aligned with empiricist views about science ( $r = -0.44, p < 0.05$  and  $r = -0.41, p < 0.05$ , respectively). In other words, compared with empiricist students, constructivist learners tended to believe that actual school laboratory environments did not greatly emphasize an open-ended approach to experimentation, nor did they integrate with theory classes. These findings are further illustrated in Figure 2, which categorizes the subjects into constructivist, mixed, and empiricist groups.

Figure 2 shows that constructivist subjects tended to perceive actual school laboratory environments less favorably than did the other two groups, except with regard to the material environment scale. This may further imply that constructivist subjects showed more dissatisfaction with the approach of laboratory activities, *per se* (e.g., the extent to which students were supportive of one another, laboratory activities were open-ended, and also integrated with nonlaboratory science classes), than with the external material support from laboratory learning environments. In particular, the differences between constructivist and empiricist students' perceptions on open-endedness and integration scales were apparent, as shown in the correlation analyses. Constructivist subjects believed that actual laboratory learning environments were presented in a less open-ended and less theory-integrated way when compared with empiricist students. These findings may have come from the strong beliefs held by constructivist students that science is open to any alternative, allowing free invention, and every observation or experimentation in science is closely related to its background theories.<sup>5</sup> Recent research suggests that students perceive their learning environments differently within a class directed by the same teacher (e.g., McRobbie, Roth, & Lucas, 1997); this study further reveals that students' SEVs may contribute to the multiple learning environments experienced by students.

<sup>5</sup> The interpretation of constructivist students' beliefs came from the in-depth interview results of a group of eighth graders who were scored higher on Pomeroy's (1993) questionnaire (i.e., having constructivist-oriented SEV). For details, refer to Tsai (1998a).

### Relationship between Students' SEVs and Perceptions of Preferred Laboratory Learning Environments

The relationship between students' SEVs and their perceptions of preferred school laboratory environments also raises some informative findings for this study. According to Table 5, students' SEVs were correlated significantly with their perceptions on the student cohesiveness and open-endedness scales of the SLEI preferred form ( $r = 0.42$ ,  $p < 0.05$  and  $r = 0.44$ ,  $p < 0.05$ , respectively). That is, constructivist students tended to show stronger preferences toward the laboratory learning environments in which students were supportive of one another and laboratory activities highlighted an open-ended approach to experimentation than empiricist students. This finding concurs with the result presented earlier indicating that, when compared with those holding empiricist-oriented SEVs, students having constructivist-oriented SEVs tended to have more frequent negotiations of meaning with their laboratory partners, an indicator of showing a preference for a student-cohesive laboratory environment. It is also consistent with the conclusions derived from Tsai's (1997) study that constructivist students showed a greater preference to learn in an instructional environment in which they could interact and negotiate with other students ( $p < 0.05$ , related to the SLEI student-cohesiveness scale), and think independently of the teacher and the other students ( $p < 0.001$ , likely associated with the SLEI open-endedness scale). Figure 3 further shows students' views of preferred laboratory learning environments among the constructivist, mixed, and empiricist groups, as defined previously.

Figure 3 reveals that constructivist students generally prefer learning in higher peer-cooperative, more open-ended theory-integrated, and better-material-supported laboratory environments, as compared with mixed and empiricist learners. In particular, the differences in subjects' views on student-cohesiveness and open-endedness scales were obvious, indicating that constructivist students enjoyed learning through interactions with their peers and exploring some unknown questions. On further examination of students' SLEI results, it was found that constructivist students' scores on the student cohesiveness scale increased markedly from the SLEI actual version to the preferred version (from an average of 23.4 to 28.1), whereas mixed and empiricist learners' scores on the same scale remained almost unchanged (an average of 26.4 and 25.3 on the SLEI actual form, and an average of 25.0 and 25.5 on the preferred form). Similar results could be found in students' views on the open-endedness scale. Constructivist subjects' scores increased greatly on the scale, from an average of 18.6 to 27.5, whereas mixed and empiricist students' scores changed slightly (21.6 and 21.7 on the actual form, 22.9 and 24.3 on the preferred form). The comparisons between students' responses on the SLEI actual form and preferred form strongly suggest that constructivist students tended to complain that actual school laboratory environments did not accommodate their learning preferences and they preferred a peer-supported, open-

**TABLE 5**  
Correlation between Students' Scientific Epistemological Views and Perceptions of Preferred Laboratory Activities ( $n = 25$ )

	SC (Preferred)	OE (Preferred)	Int (Preferred)	RC (Preferred)	ME (Preferred)
SEVs	0.42 <sup>a</sup>	0.44 <sup>a</sup>	0.13	-0.21	0.26

SC, Student-Cohesiveness scale; OE, Open-Endedness scale; Int, Integration scale; RC, Rule Clarity scale; ME, Material Environment scale.

<sup>a</sup> $p < 0.05$ .

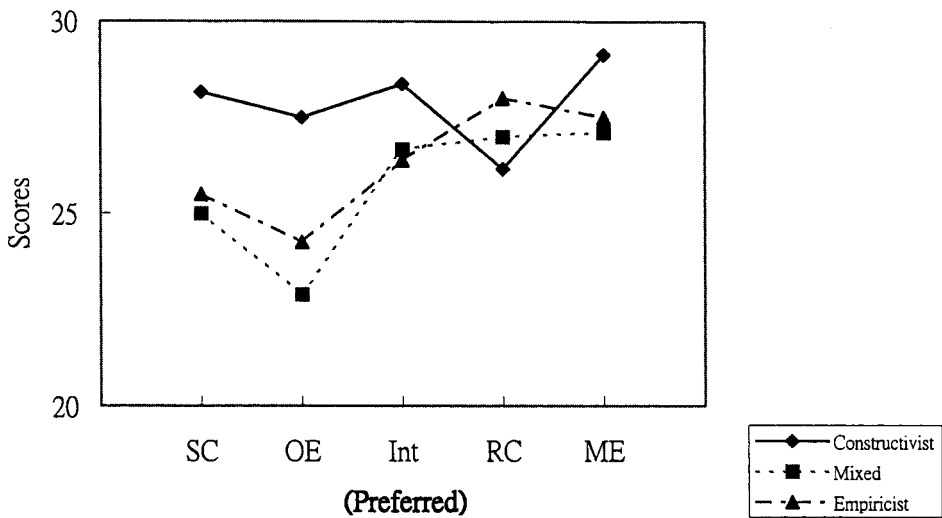


Figure 3. Students' perceptions of preferred laboratory learning environments by different SEV group subjects.

ended approach to experimentation. These students may feel frustrated by traditionally oriented school laboratory activities, which consequently influenced their performance or learning motivation in science. Science teachers need to be highly aware of students' epistemological orientations toward science in conducting laboratory activities, especially with regard to a peer-cooperative, open-ended manner of experimentation for constructivist SEV students.

### Student Interview Results

In order to obtain a more detailed picture of the interplay between students' SEVs and their learning activities in laboratory environments, all subjects were interviewed for qualitative interpretations. As found in Tsai's (1998a) study, students' interview results were basically consistent with their responses on Pomeroy's (1993) questionnaire. Their verbal expressions of students' SEVs are summarized in what follows. Empiricist students believed that science comes from accurate observations and that conceptual change in science stems mainly from the improved correctness of a new theory or greater precision of new laboratory instruments. They perceived the purpose of scientists' experiments as a fundamental way of testing the correctness of scientists' theories. On the other hand, constructivist students believed that science came from scientists' imaginations and their negotiations with other scientists, and the purpose of scientific experiments is "to explore more" or "to make the scientific theories more convincing to others." These epistemological orientations may have contributed to constructivist learners' higher frequency of negotiations of meaning in actual laboratory activities and their preference for a student-cohesive, open-ended approach to experimentation.

In the following section, subjects' typical responses about learning in school laboratory environments are presented in a more detailed way. The discussion will give every interviewee an identification, including one letter and one number. The letter indicates the subject's epistemological orientation (C for the constructivist group, M for mixed group, E for empiricist group). The subsequent number is an identifying number for each individual in a group.



First, when students were asked, “Why do science classes need laboratory exercises?” there were the following responses:

C5: The laboratory activities in science classes will help us understand the processes of science. This helps us to realize how science comes from. . . . Of course, laboratory work makes me clear about the theories presented in the teacher’s lectures and textbooks.

C3: Laboratory work helps us to view the theories in another way. It allows the theories to be presented in a more concrete way.

E4: I think the main purpose of laboratory activities is to “confirm” the facts or conclusions presented in science texts.

E5: You know, science is very objective and it exists in nature. School laboratory work provides opportunities for us to rediscover the scientific facts, if we carefully follow the correct procedures.

M3: Laboratory provides another way for us to understand science.

M4: Laboratory gives us some concrete experiences that helps us to understand the scientific concepts.

Students from each group contended that there were some linkages between school laboratory activities and theory classes. However, empiricist learners (five of them) tended to believe that, through following accurate procedures, school laboratory work was mainly used to verify the truths and validate the correctness of scientific laws, or rediscover the facts provided by their teacher or textbooks, whereas only one constructivist subject expressed a similar belief. Constructivist subjects tended to assert that school laboratory work could illustrate the constructive processes of scientific knowledge and that laboratory activities were viewed as another important way to represent scientific theories. Students’ descriptions of an ideal laboratory learning environment strengthen some of the aforementioned findings:

R: Describe [or imagine] an ideal laboratory learning environment where you felt [or feel] as though you were [or are] really learning?

C4: Students should help each other. Laboratory activities would allow more time for us to discuss. Everyone should really participate in the activities.

C6: I prefer that the teacher did not tell us “the expected experimental outcomes” before conducting the experiments. . . . I enjoy learning through really controlling the laboratory activities and through some unknown exploration. In this way, I feel I learn more.

C7: I prefer that laboratory work be related to everyday life. If we can do some experiments exploring some interesting life-related questions, it will be wonderful.

E3: We should have better experimental equipment or material support. Otherwise, our experimental results will have considerable errors and then we would not have good results.

E5: Before conducting the laboratory work, I hope the teacher would explain the processes and rules of the experiment in a very clear way. It would be better if he could conduct some demonstrations. Students should seriously obey the rules and behave well.

E6: The instruments should be accurate. Otherwise, we will have a lot of experimental errors. Because of these errors, we will not understand the purpose of the experiments.

M4: I hope to have clear rules to follow in laboratory activities. They could provide something interesting for me. The laboratory environment should be quiet.

These responses, first, reconfirm the findings concluded earlier that constructivist sub-

jects tended to prefer student-cohesive (e.g., C4, and three unlisted students) and open-ended (e.g., C6, and one unlisted student) laboratory learning environments. They also preferred exploring some life-related questions in laboratory activities (e.g., C7). On the other hand, empiricist students tended to focus on the quality of laboratory equipment (e.g., E3 and E6) and the clarity of the experimental procedures and rules (e.g., E5, and two unlisted learners; four mixed students shared the same view), consistent with their responses on the first part of interview (about their SEVs), highlighting the precision of laboratory instruments and the accuracy of observations. By and large, qualitative results showed that constructivist students seemed to be more concerned about the approach to the laboratory activities, whereas empiricist students were more interested in the quality of material support and the accuracy of experimental rules or processes, a finding mentioned earlier in the quantitative analyses.

When asked, “How do your school laboratory activities help you understand something?” constructivist students believed that school laboratory activities help them understand the content of involved scientific concepts and some other relevant concepts in a richer way (four of them) and, at the same time, they could acquire a better picture about “how scientists do or did science” (two of them). Although three empiricist students also stated a further understanding about the involved concepts as the actual function of school laboratory work for them, the rest of the empiricist students stressed that doing laboratory work made scientific concepts more outstanding and this helped them “memorize” these ideas. For example, one male empiricist subject reflected that:

The only purpose of school laboratory exercises is to help me memorize the scientific truths . . . I cannot see any other benefit of school laboratory work. Often, I think doing laboratory in science classrooms is a waste of time. If our experimental results fit the laws presented in the texts or by teachers, we have to memorize them. On the other hand, if our lab results do not fit the expected outcomes, we have to discard or distort our results, and finally try to memorize all of the “scientific truths” listed in science texts . . .

This passage exemplifies how a student’s SEVs can shape his perceptions of the goal of school laboratory activities. The learning assumption, asserting that school laboratory activities did not acknowledge other alternative thinking, could again explain why empiricist learners had a relatively low frequency of meaning negotiation when doing laboratory work, as shown earlier. Moreover, the belief that science is a collection of scientific facts may have guided the just-quoted student to misinterpret the functionality of school laboratory work and then lead him to focus on memorizing when learning science. Prior studies (e.g., Edmondson, 1989; Tsai, 1998a) revealed a similar finding that constructivist students’ learning was oriented to real understanding but empiricist students’ learning was aligned to rote memorization.

When students were asked to reflect upon their time management in school laboratory activities, constructivist students generally stated that conducting the activities, discussing experiments, and writing laboratory reports occupied most of laboratory time. Most empiricist and mixed students said that they spent most of the laboratory time manipulating material or actually “doing” laboratory work, following the codified procedures provided by textbooks. This corresponds to the observed social interactions that constructivist students had more frequent negotiations of meaning with their peers, but students in each group had similar frequencies classified as negotiations of action, and also as negotiations of material.

Students’ responses to the role they preferred most to play in school laboratory activities raised another interesting finding in this study. Constructivist students preferred to play a

variety of roles in laboratory environments. Two of them preferred to be team leaders, two of them preferred to be major actors actually conducting the experiments, two of them wanted to summarize or interpret the experimental outcomes, and still two more preferred to play various roles. For example:

C7: I think, in lab, everyone is equally important. Some have to record the data, some have to manipulate the instruments. And finally, we should discuss and reach a conclusion, and write it into lab reports. I would like to try any role. It helps me understand the laboratory work in many perspectives.

On the other hand, empiricist and mixed students generally preferred to play the role of team leaders (seven of them) and as actors who actually manipulate instruments or make observations (eight of them). Only one mixed subject and one empiricist student wanted to interpret the laboratory findings. These role-playing preferences, again, might also account for empiricists' relatively low frequency of negotiations of meaning in observed laboratory sessions.

## CONCLUSIONS

This study sought to explore the interplay between students' scientific epistemological views and their learning in school laboratory activities. It was found that most verbal interactions observed in these school laboratory activities were student–student negotiations, indicating that peers were the major actors facilitating the learning processes of laboratory activities. Although higher achievers tended to have more frequent verbal interactions directly related to laboratory activities (called “valid” negotiations), they did not show a clear tendency on particular negotiation categories defined in this study. Students' SEVs were not statistically correlated with their “valid” verbal interactions; however, students' having SEVs more oriented to constructivist views of science (constructivist students) tended to negotiate more the meaning involved in laboratory activities with their peers than those holding empirically aligned SEVs (empiricist students). Further analyses showed that constructivist students tended to engage more in interpreting or explaining the experimental outcomes, having almost half of their “valid” interactions classified as negotiations of meaning, whereas empiricist students had similar counts of negotiations in “action,” “meaning,” and “other” categories. This suggests that constructivist learners tended to contemplate more deeply the concepts involved in school laboratory activities.

Moreover, constructivist students tended to perceive actual laboratory learning environments as less open-ended and less integrated (with theory science classes) when compared to empiricist students. Also, compared to empiricist students, constructivist students tended to show stronger preferences for laboratory learning environments in which students were supportive of one another and laboratory activities emphasized an open-ended approach to experimentation. The comparisons between students' responses from the SLEI actual form and preferred form showed that constructivist students tended to complain that actual school laboratory activities did not accommodate their learning preferences and they preferred more peer-supported and open-ended environments when conducting school laboratory activities. The mismatch between actual learning environments and their preferences may severely lower constructivist students' learning motivation and, consequently, influence their academic performance in science. This suggests that science teachers should carefully consider students' epistemological views toward science when planning laboratory activities, especially with regard to creating a peer-supported atmosphere and emphasizing an open-ended manner of experimentation for constructivist students.

Qualitative details revealed that empiricist students thought that school laboratory work is used mainly to confirm the facts presented by their teacher, or data listed in science textbooks, and they tended to highlight the importance of following the experimental procedures provided by authorities. Constructivist subjects tended to contend that school laboratory work could, in some way, illustrate the constructive processes of scientific knowledge. Furthermore, constructivist students seemed to be more concerned about the approach to the laboratory activities, whereas empiricist students were more interested in the quality of material support and the correctness of experimental rules or processes. Finally, constructivists believed that school laboratory exercises helped them understand the concepts involved in a richer way, but empiricists thought that laboratory work made scientific concepts more impressive, functioning as memory aids.

Recently, science educators have become more critical of practical work in science education (refer to a mini-special issue of the *International Journal of Science Education*, Vol. 20, No. 6, 1998). Currently, most practical work in school science is referred to laboratory-based experiences. Hodson (1996) proposed that practical work in science education involves three associated purposes: (1) to help students learn science (acquiring conceptual and theoretical knowledge); (2) to help students learn about science (developing an understanding of the nature and methods of science); and (3) to enable students to do science (engaging in expertise in scientific inquiry). According to the interview results derived from this study, constructivist students seemed to conceptualize properly these purposes of practical work in laboratory activities. For example, constructivist students believe that laboratory experiences help them understand the scientific concepts involved in a richer or more concrete manner (the first purpose), understand the processes of science and where scientific knowledge came from (the second purpose), and how scientists do/did science (the third purpose). On the other hand, empiricist learners seemed to not perceive such purposes. Moreover, typical cookbook-like laboratory activities may misguide students' epistemological views toward science. Hodson (1998) cautioned that excessive use of the algorithm recipes of laboratory work leads students to believe in a method of science. Also, the very success of school science experiments reinforces the illusion of certain knowledge in science. Changing the way in which scientific knowledge is practiced in school laboratory activities may be a promising way of helping students acquire more appropriate epistemological views about science. It follows that students are expected to have greater social interactions and to develop proper perceptions regarding school laboratory work. Another interesting issue that should be further explored is investigating students' ideas of what scientists do in laboratories; that is, to study how students perceive the difference between the context of teaching and learning science and that of "doing science."

In conclusion, this study has shown that students' SEVs, in various ways, are related to their learning in laboratory activities. The findings derived from this study are, in general, consistent with the prediction proposed in the beginning of this study. When science educators have lamented that many students gain little insight in school laboratory activities, either about the major concepts involved or toward the process of knowledge construction (Novak, 1988), and that students (or even teachers) tend to follow a cookbook-type approach to experimentation and their purpose of laboratory activities is to match the truths presented in textbooks (Roth & Roychoudhury, 1994; Tobin & Gallagher, 1987; Watson, Prieto, & Dillon, 1995), this study suggests that some students' empiricist-oriented SEVs, to a certain extent, may contribute to these learning modes. It is also expected that cookbook-like laboratory work or foolproof experiments may cause epistemological conflicts for constructivist SEV students. Moreover, constructivist SEV students tended to undertake more frequent negotiations of meaning with their peers, and

to prefer student-supported and open-ended laboratory learning environments. In the educational paradigm of constructivism, science teachers are expected to create learning environments in which students could negotiate meaning, build consensus with others, and exercise deliberate and meaningful control over their learning activities (Taylor & Fraser, 1991). Research evidence has also suggested that more student–student interactions in science classes will help students to employ more meaningful learning strategies, to achieve better cognitive outcomes, to enhance learning motivation, and to develop positive attitudes toward science (Johnson & Johnson, 1989; Towns & Grant, 1997). It is plausible to anticipate that students' SEVs may be a fundamental factor influencing the success of so-called "constructivist teaching." The findings drawn from this study strongly suggest that an appropriate understanding of the constructivist epistemology of science is an important prerequisite for implementing constructivist science teaching. Science educators are encouraged to explore some of the possible ways to help students obtain constructivist-oriented epistemological views of science.

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