Development of Elementary School Students' Cognitive Structures and Information Processing Strategies Under Long-Term Constructivist-Oriented Science Instruction

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ABSTRACT: The main purpose of this study was to explore the effects of long-term constructivist-oriented science instruction on elementary school students' process of constructing cognitive structures. Furthermore, such effects on different science achievers were also investigated. The subjects of this study were 69 fifth graders in Taiwan, while they were assigned to either a constructivist-oriented instruction group or a traditional teaching group. The research treatment was conducted for 5 months, including six instructional units, and students' cognitive structures were probed through interviews coupled with a "metalistening technique" after the instruction of each unit. The interview narratives were transcribed

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into the format of "flow maps." In addition, the information processing modes shown in the flow maps were also investigated through a series of content analyses. The findings showed that the students in the constructivist-oriented instruction group attained significantly better learning outcomes in terms of the extent and integration of their cognitive structures, metacognition engagement, and the usage of information processing strategies. Moreover, it was also revealed that both high achievers and low achievers benefited from the constructivist-oriented instructional activities, but in different ways. For example, both high achievers and low achievers in the constructivist-oriented instruction group attained better usage of information processing strategies than their counterparts in traditional teaching group did; but only high achievers displayed better usage of higher order information processing modes (i.e., inferring or explaining) than their counterparts in traditional teaching group did. The results in this study finally suggest a four-stage model for students' process of constructing cognitive structure under the constructivist-oriented science instruction, including "cognitive structure acquisition," "metacognition enrichment," "cognitive structure integration," and "cognitive structure refinement." *Sci Ed* **89:**822–846, 2005

INTRODUCTION

Understanding how learners acquire knowledge is always an important issue in science education. In the last three decades, the perspectives of constructivism on learning and teaching have been strongly advocated by science educators and researchers. Constructivism is a theory about "knowing" and "learning" (Bettencourt, 1993; Bodner,1986; Fosnot, 1996), asserting that knowledge cannot be directly transmitted but must be actively constructed by learners. This view of learning also highlights the significance of the individual learner's prior knowledge in subsequent learning (Ausubel, 1968; Bischoff & Anderson, 2001; Driver & Bell, 1986). Although there are still many criticisms about constructivism (e.g., Gil-Pérez et al., 2002; Matthews, 2002; Phillips, 1995), its perspectives on learning undoubtedly have profound influences in contemporary science education (Niaz et al., 2003; Staver, 1998).

Consequently, researchers have recommended many teaching strategies or models which are based upon the assertions of constructivism to promote students' science learning, for example, concept mapping (Novak & Gowin, 1984), the learning cycle (Lawson, 2001), the POE (predict-observe-explain) strategy (Palmer, 1995; White & Gunstone, 1992), the conflict map (Tsai, 2000a, 2003), and Interpretation Construction Design Model (Black & McClintock, 1996; Tsai, 2001a). It is also proposed by educators that the integration of multiple teaching strategies could promote students' conceptual learning and knowledge construction (e.g., Bean et al., 2001; Odom & Kelly, 2001). Hence, on the basis of various constructivist-oriented science teaching strategies and models (e.g., Black & McClintock, 1996; White & Gunstone, 1992; Tsai, 2000a), the constructivist-oriented science instructional activities were developed and implemented in this study. Moreover, current practice in science education encourages the use of multiple ways to assess students' learning outcomes (Mintzes, Wandersee, & Novak, 2001). The measurement of learners' cognitive structures should be one of important indicators in assessing what they know (Tsai, 2001b), despite the fact that traditional-oriented assessment methods, such as multiple-choice question (e.g., Dimitrios & Heleni, 2002; Soyibo & Evans, 2002), matching tests, and short essay questions (Bean et al., 2001), have been widely used to evaluate learners' science learning outcomes.

Educators and cognitive scientists have tried to represent pre-acquired knowledge in terms of "cognitive structure" (Pines, 1985; West, Fensham, & Garrard, 1985). A cognitive structure is a hypothetical construct showing the extent of concepts and their relationships in a learner's long-term memory (Shavelson, 1974). Through probing learners' cognitive structures, science educators can understand what learners have already acquired. And having evidence of a learner's cognitive structure could be a fundamental step for a better understanding about how students construct knowledge (Tsai & Huang, 2002). Some science educators have included cognitive structure assessment as one of the multiple assessment modes (Shavelson, Carey, & Webb, 1990; Tsai, 2003). Therefore, students' cognitive structures were used as an assessment outcome variable in this study. In sum, the exploration of students' cognitive structures can examine their existing knowledge, the effects of teachers' instruction, and the processes of students' knowledge development.

Furthermore, longitudinal studies exploring the effects of science instruction on students' learning outcomes are rare (e.g., Novak & Musonda, 1991), especially the effects of constructivist-oriented science instruction on students' cognitive structures. The effects of constructivist-oriented science instruction or teaching strategies on students' learning outcomes were widely evaluated (e.g., Alparslan, Tekkaya, & Geban, 2003; Christianson & Fisher, 1999; Mintzes, 2001; Odom & Kelly, 2001; Schmid & Telard, 1990), but most of their treatments were conducted just for a short period of an instructional unit. However, the instructional treatments with brief duration are unlikely to bring about the desired results (Edmondson & Novak, 1993). The effects of constructivist-oriented instruction on students' learning outcomes might require a longer time to be revealed (e.g., Persall, Skipper, & Mintzes, 1997). Therefore, this study was conducted for 5 months, including six instructional units, to explore the relatively long-term effects of constructivist-oriented science instruction on the development of students' cognitive structures.

In sum, this study was conducted to examine the influences of long-term constructivist-oriented science instruction on the development of a group of Taiwanese fifth graders' cognitive structures. Moreover, previous studies conducted to explore the difference between novices and experts in science learning revealed that experts (or high achievers) always displayed more integrated cognitive structures and better usage of information processing strategies than novices (or low achievers) did (e.g., Anderson & Demetrius, 1993; Bischoff & Anderson, 1998; Tsai, 1999). Students' (prior) science achievement, at least, partially represents their general cognitive ability and performance in science, which strongly affect subsequent learning and knowledge construction (Tsai, 1998). The past science achievement plays an important role in the following process of knowledge development. Therefore, the effects of long-term constructivist-oriented science instruction on the development of different science achievers' cognitive structures were also investigated in this study.

METHOD

Subjects and Science Achievement Grouping

The subjects of this study were 69 students from two classes of an urban elementary school in Taiwan. By using a quasi-experimental research approach, one class of 35 students was assigned to a constructivist-oriented instruction group, while another class of 34 students was assigned to a traditional teaching group. Before the conduct of this study, these two groups did not show statistical differences in their science academic achievement ($p > 0.05$). And they were respectively taught by their usual science teachers (both male teachers with 2 years of science teaching).

Before the conduct of this study, some pretests were administrated to investigate whether these two groups of students showed significant differences on their preferences and perceptions of science learning environments at the beginning of this study. A posttest was also administrated to examine whether the treatment in this study could effectively provide two different learning environments between these two groups.

To assess learners' preferences and perceptions of science learning environments, the Chinese version of the *Constructivist Learning Environment Survey* (CLES), originally developed by Taylor and Fraser (1991) and adapted by Tsai (2000b), was also administered in this study. The CLES contains four scales (social negotiation scale, prior knowledge scale, autonomy scale, and student-centeredness scale), and it includes two forms, one the actual (or perceived) form and the other the preferred form. In this study, both forms were administered in the pretest, and only the actual form was used in the posttest. Tsai (2000b) reported the α-reliability of CLES to be 0.84, 0.78, 0.78, and 0.72 for the actual form, and 0.81, 0.77, 0.79, and 0.70 for the preferred form (for further details about the *Constructivist Learning Environment Survey*, see Taylor & Fraser, 1991 and Tsai, 2000b). The α-reliability was 0.72, 0.55, 0.69, and 0.67 for the actual form in this study. The alpha-reliabilities reported in this study were lower than pervious one reported by Tsai (2000b). It was likely due to the age of the respondents. Hatcher and Stepanski (1994) have claimed that, for social science studies, a Cronbach alpha coefficient even as low as 0.55 can be recognized and accepted for statistical consideration. Therefore, the reliabilities still could be viewed as adequate for the purposes of this study.

According to Tables 1 and 2, these two groups did not show statistical differences in their scores on the four scales of both the preferred form and the actual form of the CLES in the beginning of the study. Therefore, these two groups did not show statistical difference in their preferences and preconceptions of science learning environments before the conduct of the treatment in this study.

Moreover, a series of students' science standard test (like commercially available standardized tests) scores at their fourth grade were used to categorize students' science achievement in this study. The score average for all 69 participating students was used to divide the students in each class into two subgroups, one labeled the high achiever group, while the other the low achiever group. The high achiever group in the constructivist-oriented instruction group included 17 students, while that in the traditional teaching group included 19 students; and low achiever group in the constructivist-oriented instruction group included 18 students, while that in the traditional teaching group included 15 students. There was no significant difference in science achievement score for these two high achiever groups between the constructivist and traditional groups ($p > 0.05$). Similarly, no significant difference was found between the two low achiever groups ($p > 0.05$).

TABLE 1
The Comparisons of Students' Preferences of Science Learning Environment Between Constructivist and Traditional Groups in the Beginning of the Study

		Mean Per Item	*SD*	*t*
Social negotiation	Constructivist group	3.74	0.71	0.304 (n.s.)
	Traditional group	3.68	0.96	
Prior knowledge	Constructivist group	3.79	0.86	−0.177 (n.s.)
	Traditional group	3.82	0.78	
Autonomy	Constructivist group	3.33	0.90	0.708 (n.s.)
	Traditional group	3.18	0.96	
Student centeredness	Constructivist group	3.80	0.87	1.581 (n.s.)
	Traditional group	3.15	0.97	
Total score	Constructivist group	14.66	2.88	0.731 (n.s.)
	Traditional group	14.13	3.18	

n.s.: nonsignificant.

TABLE 2
The Comparisons of the Pretest on Students' Perceptions of Actual Science Learning Environment Between Constructivist and Traditional Groups in the Beginning of the Study

		Mean Per Item	*SD*	*t*
Social negotiation	Constructivist group	3.46	0.84	0.34 (n.s.)
	Traditional group	3.46	0.61	
Prior knowledge	Constructivist group	3.49	0.75	0.125 (n.s.)
	Traditional group	3.47	0.62	
Autonomy	Constructivist group	3.00	0.87	0.371 (n.s.)
	Traditional group	2.92	0.82	
Student centeredness	Constructivist group	3.39	0.81	−0.008 (n.s.)
	Traditional group	3.39	0.83	
Total score	Constructivist group	13.33	2.72	0.163 (n.s.)
	Traditional group	13.24	2.17	

n.s.: nonsignificant.

Research Treatment and Description of Lessons Taught

The research treatment was conducted for a semester, and six instructional units were implemented during this semester. In sequence, the six instructional units in this study included "the observation on the sun," "the stars," "the slight dust in the air and water," "the rocks," "musical instruments," and "basic electromagnetism." Each instructional unit was conducted about nine successive 40-min class periods (three periods per week).

Moreover, based upon various constructivist-oriented teaching strategies and models (e.g., Black & McClintock, 1996; Tsai, 2000a; White & Gunstone, 1992), the constructivist-oriented instructional activities used in this study were developed and implemented in the constructivist-oriented instructional group; while the lecture and textbook-based method was used in the traditional teaching group. For example, the POE strategy (White & Gunstone, 1992) was combined with the small group cooperative learning activities and conducted in the constructivist-oriented instruction group to promote learners' knowledge construction in the sixth instructional unit, "basic electromagnetism." First, students in the constructivist-oriented instruction group were asked to predict the results of the effect of electric current on a compass and then to write down their expected results. Subsequently, they observed the demonstration of the effect of electric current on a compass and discussed in small groups, and finally they were asked to explain the discrepancies between their predictions and observations. During these instructional activities, learners' prior knowledge was exposed for instructors and their alternative conceptions were also challenged. Students were allowed to interpret their new observations of the world around them, and then more opportunities were offered to share and negotiate their own personal interpretations.

To understand whether the treatment in this study effectively provides two kinds of different science learning environments between the constructivist-oriented and traditional groups, the actual form of the CLES was also administered immediately after the conduct of the treatment.

Cognitive Structure Exploration

Many methods of representing individual cognitive structure were proposed by educators, for example, word association, tree construction, concept map, and the flow map method.

According to the perspectives of Tsai and Huang (2002), three major aspects in describing cognitive structures were summarized, including the concepts or ideas contained, the connections among concepts, and the mode of information processing in organizing concepts. And based upon the review conducted by Tsai and Huang (2002), the flow map method, described in details later, may be the most useful method to represent learners' cognitive structures in light of the three major aspects mentioned above. Anderson and Demetrius (1993) also argued that the flow map representation required minimal intervention by interviewer and low inference for its construction, providing a convenient diagram of the sequential and multi-relation thought patterns expressed by the respondent, and it is a useful method to probe each learner's cognitive structures. Therefore, the flow map method was used to explore students' cognitive structures in this study.

There are two phases when using the flow map method (Tsai, 2001b). During the first phase of the flow map construction, a learner should be interviewed by nondirective questions to obtain an audiotaped record of his/her thoughts in order to acquire his/her ideas in the narrative. For example, in the unit of "the stars," the interview questions were as follows:

1. Please tell me what are your main ideas of "the stars."
2. Could you tell me more about the ideas you have mentioned?
3. Could you tell me the relationships between the ideas you have already told me about?

After the tape-recorded interview as described above, a "metalistening" technique can then be followed. A "metalistening" technique aims at exploring the learner's additional conceptual knowledge. With an original tape recorded interview record (i.e., the first phase), researchers can immediately replay the narrative of the learner's tape recording to provide an opportunity for the learner to recall additional concepts, which has not previously disclosed by him/herself. The learner's response in the metalistening period is also tape recorded by a second tape recorder. Thus, the "total" interview narrative, including that elicited in the metalistening period, can be further transcribed to produce a flow map, representing an individual learner's cognitive structure for each instructional unit in this study. (For the details of the flow map method and the metalistening technique, please refer to Tsai, 2001b). In this way, the researcher could obtain a more complete picture of the learner's cognitive structure in a nondirective manner and also "assess the student's metacognitive ability in reviewing his/her own ideas" (Tsai, 1998, p. 416). Students were interviewed in a week after the instruction of each unit. Therefore, six interviews were undertaken in this study.

Figure 1 shows a constructivist-oriented instruction group student's flow map after the instruction of the unit "the stars." Basically, the flow map is constructed by entering the statements in sequence uttered by the learner. The sequence of discourse is examined and recurrent ideas represented by recurring word elements in each statement (presenting a connecting node to prior idea) are linked by connecting arrows. For instance, the student's narrative mapped in Figure 1 shows a sequential pattern beginning with the differences among stars to the cause of our observation on the moving of stars. The student also stated some descriptions about the North Star. Moreover, recurrent arrows are inserted that link revisited ideas to the earliest step where the related idea first occurred. Statement 5, for example, "we can use the Big Dipper and Cassiopeia to locate the North Star" includes one revisited idea, "the North Star." Therefore, statement 5 has one recurrent arrow drawn back to statement 3 (i.e., "All stars rises from the east and set down the west; however, the North Star always stays in the north and doesn't move"; for further details about the flow map method, see Anderson & Demetrius, 1993; Tsai, 2001b; Tsai & Huang, 2001). Therefore, there are two types of arrows used in the flow map. The linear or serial arrows show the

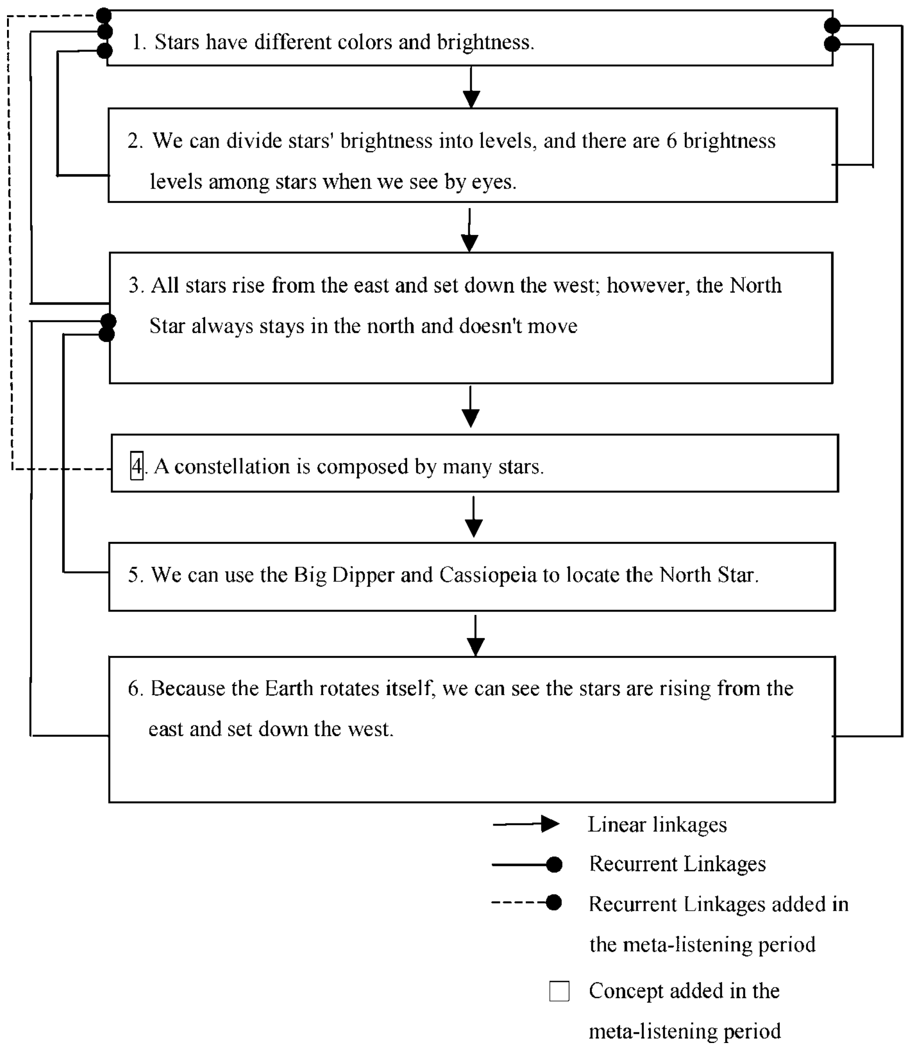

Figure 1. A flow map about "the stars" from the constructivist-oriented instruction group.

direct flow of the learner's narrative, while the recurrent arrows show the revisited ideas among the statements displayed in the flow map.

Through using the method above, students' interview narratives were transcribed into visual displays of flow maps. This study then produced 69 flow maps as the representation of students' cognitive structures about each instructional unit for the two participating classes, and a total of 414 flow maps were obtained in this study. Students' recall information analyzed through a flow map method could provide the following quantitative variables representing their cognitive structures (Tsai, 2001b):

- *Extent*: The total number of ideas in the learner's flow map, e.g., 6 in Figure 1.
- *Richness*: The total number of recurrent linkages in the learner's flow map, e.g., 7 in Figure 1.
- *Flexibility*: Flexibility indicates student's ideas change as a result of the metalistening period, equal to total number of ideas minus the number of ideas elicited before

the metalistening period, e.g., 1 in Figure 1. Metacognition is perceived as a self-regulatory skill (or relevant knowledge) whereby the learner monitors his or her own learning process (Tsai, 2001c). During the metalistening period, students can monitor and review their learning outcomes. This variable, as suggested by Tsai (1998), may provide researchers information about participants' metacognitive capacity.

- *Integratedness*: The proportion of recurrent linkages in the learner's flow map, equal to number of recurrent linkages/ (number of ideas + number of recurrent linkages), e.g., 0.54 in Figure 1.

In addition, the information processing modes shown in the flow maps were also investigated through a series of content analysis. To acquire a deeper understanding about a student's usage among different modes of information processing about the knowledge acquired from the instructional units, each of the student's statements, shown in the flow maps, was categorized into one of the following four levels of information processing modes. The categorization framework was adapted from Tsai (1999).

- *Defining*: Providing a definition of a concept or a scientific term, e.g., "A constellation is composed by many stars."
- *Describing*: Depicting a phenomenon or a fact, e.g., "There are six brightness levels among stars when we see them by eyes."
- *Comparing*: Stating the relationships between (or among) subjects, things, or methods, e.g., "All stars rise from the east and set down the west; however, the North Star always stays in the north and doesn't move."
- *Inferring or Explaining*: Describing what will happen under certain conditions or offering an account to justify the causality of two facts or events, e.g., "Because the Earth rotates, we can see the stars are rising from the east and set down the west."

In this way, the statements in each flow map were categorized. Then, the frequencies of the four-level information processing modes used by the learner were counted. As the nondirective structure of the interview protocol, it may be plausible that the extent to which the focus of the teaching was on each of the four categories of the framework is potentially significant variable on the extent to which each of the four categories was found in student responses. Students who frequently used higher order modes of information processing (i.e., "inferring or explaining") were viewed as having better strategies for organizing information during recall.

After students' interview narratives were transcribed into flow maps, the reliability of flow map diagramming of each unit was determined by asking a second independent researcher to draw a subset of students' narratives. In this study, the independent researcher was asked to transcribe a total of 90 students' narratives into flow maps (15 students' narratives for each unit). The intercoder agreements for sequential linkages of diagramming flow map for each instructional unit ranged from 0.90 to 0.94, and the total intercoder agreement was 0.94. Moreover, the inter-coder agreement of recurrent linkages for each instructional unit ranged from 0.84 to 0.94, and the total inter-coder agreement was 0.88 (for the details of calculation of the reliability coefficient, please refer to Anderson & Demetrius, 1993; Tsai & Huang, 2001). In general, it is considered sufficient for narrative analysis if the reliability is greater than 0.80. Based on this evidence, this method was deemed to be sufficiently reliable for the purpose of this study.

Similarly, the inter-coder reliability for the content analysis of information processing modes in each unit was also obtained in this study. The percentage that two researchers coded the students' ideas into the same category of information processing modes in the six instructional units was 91%, 92%, 91%, 92%, 93%, and 90%, respectively, and the total intercoder reliability (agreement) for the content analysis of information processing modes in this study was 92%. Therefore, the content analysis of information processing modes in this study was viewed as adequately reliable.

Quantitative Data Analysis

In this study, two-tailed t-test analyses were conducted to examine the statistical significances among all measure variables between groups. A level of confidence was set at a 0.05 level of significance. The t-test analyses were undertaken by using SPSS 10.0 (Statistical Package for Social Science, version 10.0).

Moreover, researchers have noticed the inadequacy of using only the result of statistical significance testing in statistical inference (Cohen, 1988). To respond to contemporary calls for improvement in the interpretation and reporting of quantitative research findings in education (e.g., Rennie, 1998), the present study also reported the practical significant (effect magnitudes) along with each statistical significance test. The Cohen's effect size index d (1988, p. 20) was used to illustrate the extent of the practical significant difference between groups for each variable in this study. The effect size index d was obtained by dividing the mean difference by the common standard deviation (1988, p. 20). Since there is no longer a common standard deviation, the formula above needs slight modification (Cohen, 1988, pp. 43–44). According to Cohen's rough characterization (1988, p. 25–27), $d = 0.2$ is deemed as a small effect size, $d = 0.5$ as a medium effect size, and $d = 0.8$ as a large effect size (for the details of effect size index d, please refer to Cohen, 1988).

In sum, statistical significance and practical significance (i.e., the coefficient of effect size) could offer different aspects of research information for the experiment in this study.

RESULTS

To present the results in this study clearly, they will be reported in the following four parts: treatment shown by CLES scores, students' cognitive structure outcomes between groups, different achievers' cognitive structure outcomes between groups, and summarization of the results.

Treatment Shown by CLES Scores

As stated previously, the actual form of the CLES was also administered immediately after the conduct of the treatment. The results of the posttest were presented in Table 3.

According to Table 3, these two groups showed statistical differences in their scores on the prior knowledge scale and the student-centeredness scale ($p < 0.05$). They also showed statistical differences in their total scores of the four scales ($p < 0.05$). These indicated that learners in the constructivist-oriented instruction group perceived a more constructivist learning environment, highlighting the importance of learners' prior knowledge and student-centered learning activities in which they had experienced. The research treatment conducted in this study, on average, provided instructional activities more aligned with the constructivist thoughts for the experimental group.

Students' Cognitive Structure Outcomes Between Groups

In this study, a series of t-test analyses were conducted to examine the differences in students' cognitive structures between the constructivist and traditional groups. Table 4

TABLE 3
The Comparisons of the Posttest on Students' Perceptions of Actual Science Learning Environment Between Constructivist and Traditional Groups

		Mean Per Item	*SD*	*t*	Cohen's *d*
Social negotiation	Constructivist group	3.48	0.68	1.162	0.28
	Traditional group	3.28	0.76		
Prior knowledge	Constructivist group	3.79	0.69	2.676[a]	0.65[b]
	Traditional group	3.29	0.84		
Autonomy	Constructivist group	3.33	0.96	0.915	0.23
	Traditional group	3.13	0.81		
Student centeredness	Constructivist group	3.84	0.81	2.756[a]	0.67[b]
	Traditional group	3.34	0.69		
Total score	Constructivist group	14.44	2.64	2.152[a]	0.52[b]
	Traditional group	13.05	2.73		

[a]$t < 0.05$.
[b]Cohen's *d* value is middle. (The Cohen's *d* value is the effect size of the practical significance between groups. The practical significance is middle when the Cohen's *d* value is between 0.5 and 0.8.)

presents the data on students' cognitive structure outcomes and their information processing modes gathered from the flow map interviews.

Extent and Richness. The results in Table 4 showed that these two groups of students had significant differences in terms of "extent" and "richness" in these six interviews ($p <$ 0.01). It indicated that students in the constructivist-oriented instruction group attained better learning outcomes after instruction, no matter in light of the extent of concepts or the richness within their cognitive structures.

Flexibility. The results in Table 4 showed that these two groups of students had significant differences in their "flexibility" of cognitive structures from the second interview to the sixth interview ($p < 0.05$). Compared with students in the traditional teaching group, those in the constructivist-oriented instruction group recalled statistically more additional concepts in the metalistening period from the second interview to the sixth interview. It seems that constructivist-oriented science instruction could help students to be more capable of monitoring his or her own process of thinking. As a result, they showed better metacognitive capacity in these interviews.

Integratedness. Table 4 also showed that in the third, the fourth, and the sixth interviews these two groups of students had significant differences in terms of "integratedness" ($p < 0.05$). It indicated that students, in the constructivist-oriented instruction group, showed more integrated cognitive structures than their counterparts in the traditional teaching group did in the interviews after these three instructional units.

Information Processing Modes. The difference in students' usages of information processing modes between these two groups was also explored. The results in Table 4 revealed that when comparing the usage of the lower order information processing modes,

TABLE 4
The Comparisons of Students' Cognitive Structure Outcomes and Information Processing Modes Between Constructivist and Traditional Groups

		Unit 1			Unit 2			Unit 3			Unit 4			Unit 5			Unit 6			Total Overall		
		Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*
Extent	Constructivist[a]	3.94	1.83	5.03**	6.89	3.61	5.40**	5.60	3.10	6.07**	6.29	3.81	5.37**	6.43	2.71	6.07**	6.34	2.85	5.71**	35.49	13.72	7.38**
	Traditional[b]	2.00	1.35		3.18	1.83		2.12	1.37		2.53	1.6		3.12	1.72		3.12	1.72		16.06	7.36	
Richness	Constructivist[a]	2.26	2.44	3.58**	2.91	2.39	2.14**	1.31	1.41	4.08**	1.83	2.31	3.97**	3.31	2.51	3.01**	4.63	3.04	4.71**	16.26	9.61	5.17**
	Traditional[b]	0.71	0.76		1.82	1.80		0.26	0.57		0.24	0.55		1.71	1.88		1.74	1.96		6.47	5.67	
Flexibility	Constructivist[a]	0.14	0.36	−0.44	1.03	1.65	3.56**	0.71	1.05	2.78**	0.80	1.08	3.96**	0.57	1.07	2.23*	0.94	1.24	3.66**	4.20	4.82	4.17**
	Traditional[b]	0.15	0.44		0.03	0.17		0.18	0.46		0.06	0.24		0.15	0.36		0.15	0.36		0.71	1.17	
Integratedness	Constructivist[a]	0.27	0.19	1.45	0.26	0.14	−0.09	0.15	0.14	3.22**	0.15	0.17	3.19**	0.30	0.14	1.12	0.35	0.14	2.32*	0.29	0.07	2.32*
	Traditional[b]	0.18	0.18		0.26	0.21		0.05	0.11		0.05	0.10		0.25	0.19		0.25	0.19		0.24	0.02	
Defining	Constructivist[a]	0.26	0.44	3.43**	0.14	0.43	1.48	0.06	0.24	0.59	1.34	1.43	3.07**	0	0	–	0	0	–	1.80	1.73	3.82**
	Traditional[b]	0	0		0.03	0.17		0.03	0.17		0.50	0.75		0	0		0	0		0.56	0.82	
Describing	Constructivist[a]	2.91	1.58	3.46**	5.40	2.88	4.86**	4.60	2.48	5.65**	4.29	3.01	4.06**	3.26	2.15	2.06*	3.83	1.84	3.70**	24.29	8.70	6.39**
	Traditional[b]	1.74	1.24		2.71	1.55		1.94	1.25		2.03	1.31		2.38	1.28		2.41	1.31		13.21	5.36	
Comparing	Constructivist[a]	0.71	0.89	2.65*	0.66	0.64	2.17*	0.49	0.74	2.95**	0.43	0.56	4.58**	2.51	1.76	6.05**	1.97	1.34	5.43**	6.77	3.65	6.98**
	Traditional[b]	0.26	0.45		0.32	0.64		0.09	0.29		0	0		0.56	0.75		0.56	0.75		1.80	2.03	
Inferring or Explaining	Constructivist[a]	0.14	0.36	1.70	0.60	0.88	3.26**	0.46	0.78	2.76**	0.23	0.43	3.17**	0.69	1.18	2.58*	0.66	1.21	2.39*	2.77	2.28	5.53**
	Traditional[b]	0.03	0.17		0.09	0.29		0.06	0.34		0	0		0.15	0.36		0.15	0.36		0.47	0.93	

Zero entry indicates no response of this kind occurred during the interview.
$^*p < .05$, $^{**}p < .01$.
[a]Constructivist-oriented instruction group ($n = 35$).
[b]Traditional teaching group ($n = 34$).

that is, "defining," these two groups of students only showed significant differences in the first interview ($p < 0.01$). Moreover, regarding "describing" and "comparing," these two groups of students had significant differences in their usage of these two modes of information processing in all six interviews ($p < 0.05$). During the last five interviews (from the second interview to the final interview), significant difference was also found in their usage of higher order modes of information processing, that is, "inferring or explaining" ($p < 0.05$). Students in the constructivist-oriented instruction group tended to store more scientific concepts in the mode of describing or comparing relevant scientific information. In general, students in the constructivist-oriented instruction group also likely organized and stored their ideas in a higher level mode of information processing, that is, "inferring or explaining."

Moreover, these two groups of students' overall total scores across all of the units were also revealed in Table 4. The results in Table 4 showed that these two groups of students had significant differences across all measures of "extent," "richness," "flexibility," and "integratedness" of their cognitive structures, and the usage of four-level information processing modes in the total overall scores across all units.

In general, compared with the students in traditional teaching group, students in the constructivist-oriented instruction group obtained better learning outcomes across all measures of "extent," "richness," "flexibility," and "integratedness" of their cognitive structures, and their usage of higher order information processing modes. That is, this study suggested that constructivist-oriented science instruction could facilitate the connections between new conceptions and pre-existing knowledge within learners' cognitive structures (especially as demonstrated by the richness and flexibility scores) and promote the usage of higher order information processing modes.

Moreover, the effect size index **d** (Cohen's d value) was also calculated to explore the practical effects of the treatment in this study (for the details of Cohen's d value, please refer to Cohen, 1988). Table 5 showed the Cohen's d values of the variables showing statistical significant differences in Table 4. According to Table 5, all the Cohen's d values of "extent" in these six interviews are large; while the Cohen's d values of the "richness" in the second and the fifth interviews are middle and others are large. The Cohen's d values of "flexibility" are large in the second, the fourth, and the sixth interviews, and they are middle in the third and the fifth interviews. The Cohen's d values of "integratedness" are middle in the third,

TABLE 5
The Cohen's *d* Values of Students' Cognitive Structure Outcomes and the Usage of Higher Order Information Processing Modes Between Constructivist and Traditional Groups

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Total Overall
Extent	1.20**	1.30**	1.45**	1.29**	1.46**	1.37**	1.76**
Richness	0.86**	0.52*	0.98**	0.95**	0.72*	1.10**	1.24**
Flexibility	–	0.85**	0.65*	0.95**	0.53*	0.87**	1.00**
Integratedness	–	–	0.77*	0.75*	–	0.60*	0.97**
Higher order information processing modes (i.e., inferring or explaining)	–	0.78*	0.67*	0.76*	0.62*	0.57*	1.32**

The Cohen's *d* value is the effect size of the practical significance between groups. The practical significance is large when the Cohen's *d* value is larger than 0.8, and the practical significance is middle when the Cohen's *d* value is between 0.5 and 0.8.

*Cohen's *d* value is middle; **Cohen's *d* value is large.

the fourth, and the final interviews. Moreover, the Cohen's d values of students' usage of higher order information processing modes (i.e., "inferring or explaining") are middle from the second to the sixth interview. According to Table 5, the Cohen's d values of students' total overall scores across all the units in "extent," "richness," "flexibility," "integratedness," and the usage of higher order information processing modes (i.e., "inferring or explaining") are large.

Different Achievers' Cognitive Structure Outcomes Between Groups

The differences in high achievers' cognitive structure outcomes between the constructivist and traditional groups were explored by conducting t-test analyses. Similarly, a series of t-tests were conducted to investigate whether the low achievers in the constructivist-oriented instruction group outperformed their counterparts in the traditional teaching group on the cognitive structure outcomes. Table 6 presents the data on the high achievers' cognitive structure outcomes and their information processing modes between two instructional groups, and Table 7 presents the data on the analyses of low achievers' outcomes between groups.

Extent and Richness. The results in Table 6 showed that there were significant differences in terms of "extent" between these two high achiever groups after the instruction of each unit ($p < 0.01$). The results in Table 7 also showed that these two groups of low achievers also had significant differences in the "extent" of their cognitive structures in all of the six interviews ($p < 0.01$). These results indicated that both the high and low achievers in the constructivist-oriented instruction group obtained more concepts or ideas than their counterparts in the traditional teaching group did.

Table 6 also revealed that there were significant differences in terms of "richness" between the two high achiever groups in all of the six units ($p < 0.01$). It indicated that constructivist-oriented science instruction may have helped high achievers develop not only more extended cognitive structures, but also richer cognitive structures than the traditional teaching did. However, the results in Table 7 showed that these two groups of low achievers only had significant differences in the "richness" of their cognitive structures in the third and sixth interview ($p < 0.05$). That is, low achievers in the constructivist-oriented instruction group did not constantly acquire richer cognitive structures in these six interviews than their counterparts in the traditional teaching group.

Flexibility. According to Tables 6 and 7, these two groups of high achievers had significant differences in their "flexibility" of cognitive structures ($p < 0.05$) in four interviews (i.e., the second, the third, the fourth, and the sixth interviews); but no significant difference was found between these two groups of low achievers in any interview. The flexibility of cognitive structures revealed in this study may be related to the students' metacognition engagement. It might imply that high achievers benefited more from the constructivist-oriented science instruction in enhancing their metacognitive capacity.

Integratedness. The results in Table 6 showed that these two groups of high achievers had significant differences in terms of "integratedness" from the third to the sixth interviews ($p < 0.01$). That is, high achievers in the constructivist-oriented instruction group developed more integrated cognitive structures than those in the traditional teaching group from unit

TABLE 6
The Comparisons of High Achievers' Cognitive Structure Outcomes and Information Processing Modes Between Constructivist and Traditional Groups

		Unit 1			Unit 2			Unit 3			Unit 4			Unit 5			Unit 6			Total Overall		
		Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*
Extent	Con-high[a]	4.41	1.66	5.18**	8.53	2.85	6.26**	6.24	2.05	6.30**	8.18	3.23	5.94**	7.29	2.62	4.99**	8.06	2.59	6.04**	42.71	11.27	7.72**
	Trad-high[b]	1.89	1.24		3.42	2.01		2.53	1.47		3.11	1.49		3.53	1.90		3.53	1.90		18.00	7.78	
Richness	Con-high[a]	3.00	2.35	4.05**	3.94	2.46	2.20*	1.71	1.26	3.72**	2.88	2.60	4.08**	4.35	2.76	3.23**	6.12	2.98	4.91**	22.00	9.55	5.57**
	Trad-high[b]	0.63	0.60		2.32	1.97		0.42	0.69		0.26	0.56		1.74	2.08		1.79	2.20		7.16	6.28	
Flexibility	Con-high[a]	0.24	0.44	0.57	1.59	1.42	4.66**	1.18	1.29	2.71*	1.29	1.21	4.16**	0.71	1.26	1.72	1.41	1.46	3.44**	6.41	5.68	3.94**
	Trad-high[b]	0.16	0.37		0.05	0.23		0.26	0.56		0.05	0.23		0.16	0.37		0.16	0.37		0.84	1.38	
Integratedness	Con-high[a]	0.33	0.19	1.85	0.29	0.10	−0.50	0.20	0.12	2.79**	0.22	0.16	3.83**	0.34	0.12	2.28*	0.40	0.10	3.64**	0.32	0.07	2.85**
	Trad-high[b]	0.19	0.18		0.32	0.21		0.08	0.13		0.05	0.09		0.23	0.16		0.23	0.17		0.25	0.09	
Defining	Con-high[a]	3.35	0.49	2.95**	0.24	0.56	1.25	0.12	0.33	1.46	1.65	1.50	2.57*	0	0	–	0	0	–	2.35	1.73	3.63**
	Trad-high[b]	0	0		0.05	0.23		0	0		0.63	0.68		0	0		0	0		0.68	0.82	
Describing	Con-high[a]	3.06	1.52	3.18**	6.59	2.48	5.40**	5.00	1.54	5.65**	5.53	2.79	4.18**	3.18	1.91	0.78	4.53	1.87	3.11**	27.88	7.54	5.85**
	Trad-high[b]	1.68	1.06		2.84	1.64		2.26	1.37		2.47	1.22		2.74	1.45		2.79	1.47		14.79	5.87	
Comparing	Con-high[a]	1.00	1.06	3.00**	0.82	0.73	1.70	0.71	0.92	2.29*	0.65	0.61	4.40**	3.00	2.09	4.65**	2.65	1.27	6.10**	8.82	3.84	6.88**
	Trad-high[b]	0.21	0.42		0.42	0.69		0.16	0.37		0	0		0.53	0.70		0.53	0.70		1.84	1.74	
Inferring or Explaining	Con-high[a]	0.24	0.44	1.54	0.76	0.83	2.77*	0.41	0.62	1.67	0.35	0.49	2.95**	1.12	1.45	2.48*	1.18	1.55	2.49*	4.06	2.08	5.90**
	Trad-high[b]	0.05	0.23		0.16	0.37		0.11	0.46		0	0		0.21	0.42		0.21	0.42		0.74	1.10	

Zero entry indicates no response of this kind occurred during the interview.
$^{*}p < 0.05$, $^{**}p < 0.01$
[a]High achievers in constructivist-oriented instruction group ($n = 17$).
[b]High achievers in traditional teaching group ($n = 19$).

TABLE 7
The Comparisons of Low Achievers' Cognitive Structure Outcomes and Information Processing Modes Between Constructivist and Traditional Goups

		Unit 1			Unit 2			Unit 3			Unit 4			Unit 5			Unit 6			Total Overall		
		Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*	Mean	*SD*	*t*
Extent	Con-low[a]	3.50	1.92	2.42*	5.33	3.63	2.44*	5.00	3.80	3.63**	4.50	3.50	2.97**	5.61	2.62	4.03**	4.72	2.05	3.43**	28.67	12.48	4.50**
	Trad-low[b]	2.13	1.51		2.87	1.60		1.60	1.06		1.80	1.47		2.60	1.35		2.60	1.35		13.60	6.17	
Richness	Con-low[a]	1.56	2.38	1.15	1.94	1.92	1.25	0.94	1.47	2.48*	0.83	1.47	1.69	2.33	1.81	1.09	3.22	2.41	2.11*	10.83	5.91	2.74**
	Trad-low[b]	0.80	0.94		1.20	1.37		0.07	0.26		0.20	0.56		1.67	1.68		1.67	1.68		5.60	4.87	
Flexibility	Con-low[a]	0.06	0.24	−0.57	0.50	1.72	1.23	0.28	0.46	1.66	0.33	0.69	1.53	0.44	0.86	1.41	0.50	0.79	1.78	2.11	2.56	2.46*
	Trad-low[b]	0.13	0.52		0	0		0.07	0.26		0.07	0.26		0.13	0.35		0.13	0.35		0.53	0.83	
Integratedness	Con-low[a]	0.21	0.17	0.36	0.23	0.16	0.60	0.11	0.14	2.35*	0.09	0.16	0.96	0.26	0.14	−0.33	0.29	0.16	0.21	0.26	0.06	0.80
	Trad-low[b]	0.16	0.19		0.19	0.19		0.02	0.06		0.04	0.12		0.28	0.21		0.28	0.21		0.23	0.14	
Defining	Con-low[a]	0.17	0.38	1.84	0.06	0.24	0.91	0	0	−1.00	1.06	1.35	1.89	0	0	–	0	0	–	1.28	1.60	2.02
	Trad-low[b]	0	0		0	0		0.07	0.26		0.33	0.82		0	0		0	0		0.40	0.83	
Describing	Con-low[a]	2.78	1.66	1.77	4.28	2.85	2.15*	4.22	3.12	3.46**	3.11	2.78	2.11*	3.33	2.40	2.17*	3.17	1.58	2.82**	20.89	8.51	4.30**
	Trad-low[b]	1.80	1.47		2.53	1.46		1.53	0.99		1.47	1.25		1.93	0.88		1.93	0.88		11.20	3.97	
Comparing	Con-low[a]	0.44	0.62	0.57	0.50	0.51	1.60	0.28	0.46	2.58*	0.22	0.43	2.20*	2.06	1.26	3.84**	1.33	1.08	2.15*	4.83	2.12	3.94**
	Trad-low[b]	0.33	0.49		0.20	0.56		0	0		0	0		0.60	0.83		0.60	0.83		1.73	2.40	
Inferring or	Con-low[a]	0.06	0.24	0.91	0.44	0.92	2.05	0.50	0.92	2.30*	0.11	0.32	1.46	0.28	0.67	1.23	0.17	0.38	0.86	1.56	1.76	3.27**
Explaining	Trad-low[b]	0	0		0	0		0	0		0	0		0.07	0.26		0.07	0.26		0.13	0.52	

Zero entry indicates no response of this kind occurred during the interview.
$^{*}p < 0.05$, $^{**}p < 0.01$
[a]Low achieves in constructivist-oriented instruction group ($n = 18$).
[b]Low achiever subgroup in traditional teaching group ($n = 15$).

3 to unit 6. However, significant difference was found between these two low achiever groups only in the third interview ($p < 0.05$). In general, compared with the traditional teaching, the constructivist-oriented science instruction in this study could facilitate high achievers to develop more integrated cognitive structures, especially after an earlier stage of its implementation in science classrooms.

Information Processing Modes. The results in Tables 6 and 7 revealed that these two groups of high achievers only had significant differences in their usage of lower order information processing, that is, "defining" in the first and the fourth interviews ($p < 0.05$, Table 6); but these two groups of low achievers did not have significant differences in their usage of lower order information processing in these six interviews (Table 7).

Moreover, high achievers in the constructivist-oriented instruction group showed significantly better usage in the information processing mode of "describing" in five interviews (i.e., the first, second, third, fourth, and the sixth interviews, $p < 0.01$) than their counterparts did, and these two groups of low achievers also had significant differences in their usage of the information processing mode "describing" in five interviews (from the second to the sixth interviews, $p < 0.05$).

Tables 6 and 7 revealed that there were significant differences between these two high achiever groups in their usage of the "comparing" information processing mode in five interviews (the first, the third, the fourth, the fifth, and the sixth interviews, $p < 0.05$); and there were also significant differences between these two low achiever groups in their usage of the same information processing mode from the third interview to the sixth interview ($p < 0.05$).

Furthermore, significant differences were also found in high achievers' usage of higher order modes of information processing mode "inferring or explaining" in four interviews (the second, the fourth, the fifth, and the final interview, $p < 0.05$); but the two groups of low achievers only had significant differences in their usage of "inferring or explaining" in the third interview ($p < 0.05$). It seemed to imply that both high and low achievers might benefit from the constructivist-oriented science instruction in their usage of information processing modes, but in different ways. Especially, high achievers in the constructivist-oriented instruction group were more likely to display better usage of higher order information processing mode (i.e., "inferring or explaining") than their counterparts in the traditional teaching group did.

Moreover, the results in Table 6 showed that these two high achiever groups of students showed significant differences across all measures of "extent," "richness," "flexibility," and "integratedness" of their cognitive structures, and the usage of four-level information processing modes in the total overall scores across all the units; while Table 7 also revealed that there were significant differences between these two low achiever groups in their total overall scores (across all the units) in "extent," "richness," "flexibility," and the usage of information processing modes, "describing," "comparing," and "inferring or explaining." However, these two low achiever groups of students did not show significant difference in their total overall scores (across all the units) in "integratedness" and the usage of information processing mode, "defining."

In sum, high achievers in the constructivist-oriented instruction group showed statistically better learning outcomes no matter in the "extent," "richness," "flexibility," and "integratedness" of their cognitive structures and the usage of higher order information processing modes than their counterparts in the traditional teaching group did. On the other hand, low achievers in the constructivist-oriented instruction group attained significantly better learning outcomes in the "extent" of their cognitive structures and the usage of lower order and middle order information processing modes (i.e., "defining," "describing," and "comparing") than their counterparts in the traditional teaching group did. The findings in this study also revealed that both high achievers and low achievers in the constructivist-oriented instruction group attained better usage of information processing modes, but in somewhat different ways. Low achievers displayed better usage of the lower order (i.e., "describing") and middle order (i.e., "comparing") information processing modes; however, only high achievers in the constructivist-oriented instruction group attained better usage of the higher order information processing modes. Moreover, it is argued that low (or middle) order cognitive operations (such as "comparing") may act as precursors to the development of higher order operations and increasingly replaced by higher order operations (Bischoff & Anderson, 2001). The observed usage of the higher order information processing modes was likely due to the fact that the learners (especially higher achievers) in the constructivist science classrooms would need more complex cognitive structures to store more concepts or ideas they have learned. Thus, higher order information processing modes were largely used in the constructivist instruction to organize their concepts or ideas.

To explore the practical effects of the treatment in this study, the effect size index **d** (Cohen's *d* value) was also calculated. Table 8 showed the Cohen's *d* values of the variables in which the two subgroups of high achievers had significant differences in Table 6, and Table 9 showed the Cohen's *d* values for the variables with significant differences on the two low achiever subgroups in Table 7.

According to Table 8, high achievers' Cohen's *d* values of "extent" in all of these six units are large; and their Cohen's *d* values of "richness" is middle in unit 2 and large in the other five units. Their Cohen's *d* values of "flexibility" are large in units 2, 3, 4, and 6. Moreover, high achievers' Cohen's *d* value of "integratedness" is middle in unit 5, and large in units 3, 4, and 6. The Cohen's *d* values of their usage of higher order information processing modes (i.e., "inferring or explaining") are large in units 2, 4, 5, and 6. Moreover, the Cohen's *d* values of high achievers' total overall scores (across all the units) in "extent," "richness," "flexibility," "integratedness," and the usage of higher order information processing modes (i.e., "inferring or explaining") are large.

Table 9 revealed that low achievers' Cohen's *d* values of "extent" are also large in all of these six units; but their Cohen's *d* value of "richness" is large in unit 3 and middle in unit 6. Their Cohen's *d* value of "integratedness" is large in unit 3. Furthermore, the Cohen's *d*

TABLE 8
The Cohen's *d* Values of High Achievers' Cognitive Structure Outcomes and Information Processing Modes Between Constructivist and Traditional Groups

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Total Overall
Extent	1.72**	2.07**	2.08**	2.02**	1.64**	1.99**	1.32**
Richness	1.38**	0.73*	1.27**	1.39**	1.07**	1.65**	2.55**
Flexibility	–	1.51**	0.93**	1.42**	–	1.17**	1.84**
Integratedness	–	–	0.94**	1.32**	0.77*	1.22**	1.35**
Higher order information processing modes (i.e., inferring or explaining)	–	0.93**	–	1.01**	0.85**	0.85**	2.00**

The Cohen's *d* value is the effect size of the practical significance between groups. The practical significance is large when the Cohen's *d* value is larger than 0.8, and the practical significance is middle when the Cohen's *d* value is between 0.5 and 0.8.

*Cohen's *d* value is middle, **Cohen's *d* value is large.

TABLE 9
The Cohen's *d* Values of Low Achievers' Cognitive Structure Outcomes and Information Processing Modes Between Constructivist and Traditional Groups

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Total Overall
Extent	0.91**	0.87**	1.22**	1.01**	1.44**	1.22**	1.53**
Richness	–	–	0.83**	–	–	0.75*	0.97**
Flexibility	–	–	–	–	–	–	0.83**
Integratedness	–	–	0.86**	–	–	–	–
Higher order information processing modes (i.e., inferring or explaining)	–	–	0.77*	–	–	–	1.10**

The Cohen's *d* value is the effect size of the practical significance between groups. The practical significance is large when the Cohen's *d* value is larger than 0.8, and the practical significance is middle when the Cohen's *d* value is between 0.5 and 0.8.
*Cohen's *d* value is middle, ** Cohen's *d* value is large.

value of low achievers' usage of higher order information processing modes (i.e., "inferring or explaining") is middle in unit 3. The Cohen's *d* values of total overall scores (across all the units) in "extent," "richness," "flexibility," and the usage of higher order information processing modes (i.e., "inferring or explaining") are large.

Summarization of the Results: Initial Interpretation for Student Learning Trends

The various occurrences of significant differences between groups on the student measures across six units may have suggested the learning trends of students' process of constructing cognitive structures under constructivist-oriented science instruction. One might argued that the different content and instruction order of the units could be the source of differences on students' cognitive structure outcomes in the six units. In other words, the differences on students' cognitive structures throughout the six units could not provide strong evidence for a clear learning trend. However, these results were acquired by comparing cognitive structure outcomes of two groups of students in the six units; that is, they were obtained on the basis of comparative (relative) results, not absolute results. Therefore, the results might be plausible to provide some initial evidence for students' learning trends on the process of constructing cognitive structures under the constructivist-oriented science instruction. Some perceived features of students' learning trend, presented below, is intended to construct a pioneering model to describe students' learning processes under the constructivist-oriented science instruction.

By integrating the results of Tables 4 and 5, this study further demonstrated the learning trends on students' process of constructing cognitive structures under the constructivist-oriented science instruction. The following criteria were employed to ascertain whether students display *significant learning trends* on their cognitive structure variables under the constructivist-oriented science instruction. In this study, it would be viewed that learners showed a significant learning trend on a variable of their cognitive structures, if the following conditions are both fulfilled: First, students in the constructivist-oriented group and those in the traditional group had a statistically significant difference in a variable for three (or more) successive interviews. Second, among each set of three successive interviews, at least two of the Cohen's *d* values should be large, and the other should be at least middle. For example, these two groups of students had statistically significant difference in "flexibility" of their cognitive structures from the second to the sixth interview (for five successive interviews), and the Cohen's *d* values of "flexibility" are large, middle, large, large, and middle respectively from the second to the sixth interview. Therefore, students in the constructivist-oriented group displayed a significant learning trend on the "flexibility" of their cognitive structures from unit 2 and the trend lasted from unit 2 to unit 6. These two groups of students also showed statistically significant difference in their usage of higher order information processing modes (i.e., "inferring or explaining") from the second to the sixth interview (for five successive interviews). However, none of the Cohen's *d* value for this variable is large. Hence, based on the criteria presented previously, the significant learning trend on their usage of higher order information processing modes (i.e., "inferring or explaining") did not appear throughout the study.

By a series of similar analyses above, the occurrences of the significant learning trends of students' process of constructing cognitive structures under the constructivist-oriented science instruction were summarized as Figure 2. According to Figure 2, the students under the constructivist-oriented science instruction displayed significant learning trends on both the "extent" and "richness" of their cognitive structures from the first to the final instructional unit. Moreover, they also showed the significant learning trend on the "flexibility" of their cognitive structures from the second to the final instructional unit. Hence, both the significant learning trends on the "extent" and "richness" of students' cognitive structures appeared before the learning trend on the "flexibility." However, the significant learning trend on the "integratedness" of students' cognitive structures and the usage of higher order information processing modes did not be revealed in this study.

Also, by integrating the results of Tables 6 and 8, this study further demonstrated the learning trends of high achievers' process of constructing cognitive structures under the

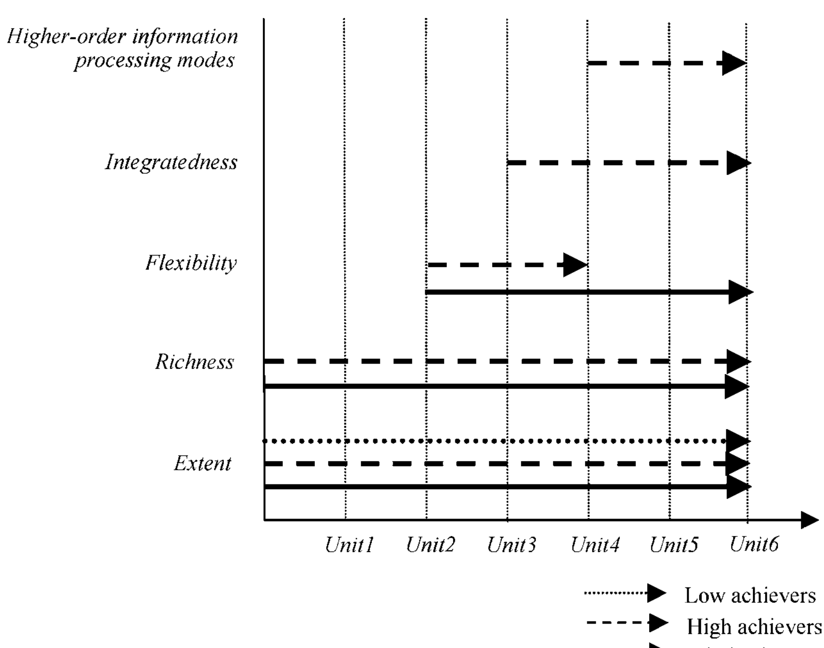

Figure 2. Students' learning trends on cognitive structure variables in the constructivist-oriented instruction group.

constructivist-oriented science instruction. The criteria presented previously were also used to examine the occurrence of the significant learning trends of high achievers' cognitive structures, also shown by Figure 2.

According to Figure 2, high achievers under the constructivist-oriented science instruction displayed significant learning trends on both the "extent" and "richness" of their cognitive structures from unit 1 to unit 6. They also showed a significant learning trend on the "flexibility" of their cognitive structures from unit 2 to unit 4, and a significant developmental trend on the "integratedness" of their cognitive structures from unit 3 to unit 6. In addition, a significant learning trend was also observed on their usage of higher order information processing modes (i.e., inferring or explaining) from unit 4 to unit 6. In sum, both the significant learning trends on the "extent" and "richness" of their cognitive structures occurred first. Sequentially, the significant learning trends on high achievers' "flexibility," "integratedness" of cognitive structures, and their usage of higher order information processing modes (i.e., "inferring or explaining") occurred. However, the significant learning trend on the "flexibility" of their cognitive structures disappeared in units 5 and 6.

Similarly, by integrating the results of Tables 7 and 9, this study also demonstrated the learning trends of low achievers' process of constructing cognitive structures under the constructivist-oriented science instruction, illustrated in Figure 2. According to Figure 2, the low achievers under the constructivist-oriented science instruction in this study only displayed the significant learning trend on the "extent" of their cognitive structures from unit 1 to unit 6.

DISCUSSION AND IMPLICATIONS

The findings of this study revealed that constructivist-oriented science instruction could promote students' performance in science learning in light of cognitive structure outcomes. Students in the constructivist-oriented instruction group attained significantly better leaning outcomes no matter in terms of the extent, the richness, and the integratedness of their cognitive structures, the usage of metacognition, and the information processing strategies. Moreover, earlier research work has suggested that high academic achievers and low academic achievers have significant differences in the integration of their cognitive structures and the usage of information processing strategies (Anderson & Demetrius, 1993; Bischoff & Anderson, 1998, 2001; Tsai, 1998, 1999; Tsai & Huang, 2001). The findings derived from the present study also showed that both high achievers and low achievers benefited from the constructivist-oriented instructional activities, nevertheless in different ways. High achievers benefited from these activities on all of cognitive structure variables considered in this study; however, low achievers benefited from these activities only on the extent of their cognitive structures. In sum, high achievers and low achievers under the constructivist-oriented science instruction revealed different effects on their metacognitive engagement, connection of cognitive structures, and the usage of higher order information processing strategies in this study.

The data gathered from this study also likely suggest a four-stage model for the process of developing cognitive structure under the constructivist-oriented science instruction. The effects of constructivist-oriented science instruction for high achievers, shown in Figure 2, may illustrate a more detailed picture about the process of constructing cognitive structure. On the basis of Figure 2, this study proposed a four-stage model for students' process of constructing cognitive structures under the constructivist-oriented science instruction, illustrated in Figure 3. These stages are "cognitive structure acquisition," "metacognition enrichment," "cognitive structure integration," and "cognitive structure refinement," and the features of these stages are presented in Table 10.

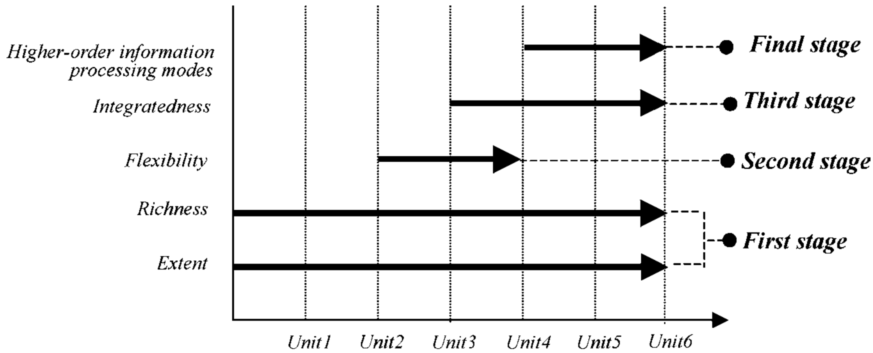

Figure 3. The four stages of the process of developing cognitive structure under the constructivist-oriented instruction.

Based on the research data in this study, students in the constructivist-oriented group, on average, were probably in the second stage at the end of this study. Low achievers in the constructivist-oriented instruction group probably remained in the first stage throughout the study. However, high achievers may have experienced the four stages, and have attained the fourth stage at the end of this study.

Moreover, Tsai and Huang (2001) proposed a three-stage model for the learners' acquisition of science knowledge. These stages are "knowledge development," "knowledge extension," and "knowledge refinement." The model proposed by Tsai and Huang (2001) is based on the results under conventional science instruction; but the model revealed in this study was suggested particularly under the constructivist science instruction. These two models are also compared in Table 11, suggesting that the learning features of the three stages proposed by Tsai and Huang (2001) are respectively similar to the first, the third, and the final stages of the model proposed in this study. The model proposed in this study could be viewed as a refined one of Tsai and Huang (2001).

Although the four stages proposed in this study can effectively describe the process of constructing cognitive structure under the constructivist-oriented science instruction, and then possibly provide a general model for learners' process of developing cognitive structures. However, it needs to be acknowledged that it is possible that the observed difference or learning trend among the units was caused by the content of the units or their serial order. Also, the nonsignificant differences on some measures are likely due to the low power

TABLE 10
The Four-Stage Model of the Process of Constructing Cognitive Structure Under the Constructivist-Oriented Science Instruction

Stage	Cognitive Structure Acquisition	Metacognition Enrichment	Cognitive Structure Integration	Cognitive Structure Refinement
Stage feature	A learning trend is revealed on learners' "extent" and "richness" of their cognitive structures.	A learning trend is shown by learners' "flexibility" of their cognitive structures.	A learning trend is revealed on learners' "integreatedness" of their cognitive structures.	A learning trend is displayed by learners' usage of higher order information processing modes.

TABLE 11
Comparison of the Model A Proposed in this Study and the Model B Proposed by Tsai and Huang (2001)

Feature	Extent of Knowledge	Metacognitive Capacity	Integratedness of Knowledge	Higher Order Information Processing
Model A	Cognitive structure acquisition stage	Metacognition enrichment stage	Cognitive structure integration stage	Cognitive structure refinement stage
Model B	Knowledge development stage	–	Knowledge extension stage	Knowledge refinement stage

resulting from the moderate *n* (for example, in Table 7, column labeled "unit 1," second row entry on "richness," the mean difference is almost double, but the SD is large and there is no significant difference). Therefore, the four-stage model only could be viewed as an initial one to illustrate learners' learning trends on the process of constructing cognitive structure. More following-up studies, clearly, should be conducted to examine the robustness of this model.

Bischoff and Anderson (2001) have argued that sufficient concepts or ideas seem to precede and promote the development of more complex ideational patterns in the learner's cognitive structure. In the first stage of the model above, the constructivist-oriented instruction helps learners develop more extended knowledge frameworks, whereas learners display more integrated cognitive structures in the third stage. These extended knowledge structures, likely serving as a scaffold, may facilitate the construction of more integrated cognitive structures in the later stage of cognitive structure development. Therefore, the model revealed in this study is consistent with the aforementioned argument proposed by Bischoff and Anderson (2001). Moreover, Dole and Sinatra (1998) proposed that the usage of metacognition has a profound influence on learners' cognitive learning outcomes, and a meaningful processing or refinement of information should be involved in metacognitive activities. Consequently, the usage of metacognition likely plays an essential role in the process of constructing cognitive structure. The metacognitive engagement as utilized in the second stage of the process of constructing cognitive structure may be an important base for the construction of more integrated cognitive structures and advanced usage of higher order information processing strategies in later stages. Tsai and Huang (2001) also proposed that the use of higher order information processing strategies and the increase in networking connections among existing concepts should mutually reinforce one another. The findings stemmed from the present study likely indicated that the constructivist-oriented instruction could promote learners to use more generalized or advanced forms of knowledge (e.g., explaining) to express their understanding of the science concepts, as their cognitive structures gradually become more elaborative and connected, particularly for high achievers.

Moreover, Mintzes, Wandersee, and Novak (1998) also argued that inadequate metacogniton is a major barrier to learning, and it can be developed with appropriate learning experiences, such as learning with the POE strategy, concept maps, and Vee diagrams. In other words, learners may improve their metacognitive capacity (including knowledge, beliefs, strategies, and behaviors) under the constructivist-oriented science instruction, as the POE strategy (White & Gunstone, 1992) and the conflict map (Tsai, 2000a, 2003) and other proper learning experiences are provided in the instruction. However, further explorations are suggested to investigate the refined relationships among learners' metacognition engagement, their integration of cognitive structures, and their usage of higher order information processing modes.

The constructivist-oriented science instruction implemented in this study has integrated many teaching activities and approaches by science educators. Hence, it is suggested that instructors should utilize multiple constructivist teaching strategies and combine a variety of instructional activities to promote learners' cognitive structure development and knowledge construction in science classrooms. Particularly, instructors should help learners develop more integrated cognitive structures by paying more attention to making the connections between students' prior knowledge and instructional materials. This study has also suggested that the metacognitive awareness of students' learning process is also important. Teachers should help students monitor and review their learning process, thus enhancing their metacognitive ability during learning. Moreover, teachers should encourage students to use higher order information processing modes, which help them to develop richer and more integrated cognitive structures.

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