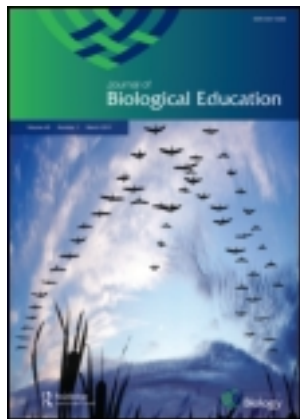


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Effects of constructivist-oriented instruction on elementary school students' cognitive structures

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The purpose of this study was primarily to explore the effects of constructivist-oriented instruction on fifth graders' cognitive structures about biological reproduction. Furthermore, such effects on different science achievers were also investigated. The subjects of this study were 69 eleven year olds in Taiwan, who were assigned to either a constructivist-oriented instruction group or a traditional teaching group. The research treatment was conducted for three weeks, and the interview data were gathered a week later after the instruction about biological reproduction. The interview narratives were transcribed into 'flow maps'. The information processing modes shown in the flow maps were also investigated through a series of content analysis. The results of this study revealed that students in the constructivist-oriented instruction group, in general, attained better learning outcomes about biological reproduction after instruction, both in terms of the extent of concepts and in the richness within their cognitive structures. Furthermore, the students in this group were probably better organised and stored their ideas in a higher-level mode of information processing, especially in the mode of 'inferring or explaining'. However, high achievers and low achievers in the constructivist-oriented instruction attained better usage of information processing modes in somewhat different ways; only high achievers in the constructivist-oriented instruction group attained significantly better usage of high-order information processing modes.

Key words: Constructivist; Cognitive structure; Flow map; Biological reproduction; Taiwan

Introduction

Constructivism is a theory about 'knowing' and 'learning' (Bodner, 1986; Bettencourt, 1993; Fosnot, 1996), asserting that knowledge cannot be directly transmitted but must be actively constructed by learners. This view of learning also emphasises the significance of each individual learner's previous knowledge in subsequent learning (Ausubel, 1968; Driver and Bell, 1986; Bischoff and Anderson, 2001). There is no doubt that the perspectives of constructivism in learning and teaching have profound influences on the development of science curriculum and science teaching practice (Matthews, 2002; Staver, 1998).

In the past three decades, 'meaningful learning' has been strongly advocated by science educators (e.g., Ausubel, 1968; Mintzes *et al*, 1998). Among biology teachers and educators, there seems to be a growing recognition of the need to refocus on students' learning outcomes derived from meaningful learning and their conceptual understanding of biological ideas (Mintzes *et al*, 2001). It is also suggested that constructivist-oriented instruction or strategies can promote students' meaningful learning (Taylor and Fraser, 1991; Tsai, 1998, 1999, 2003). Therefore, many teaching strategies based upon the assertions of constructivism have been adopted in biological education, and many of

these teaching strategies have been shown to improve students' performance in biological learning, for example, concept mapping (Kinchin, 2000; Schmid and Telaro, 1990), the learning cycle (Lawson, 2001), cooperative learning strategies (Soyibo and Evans, 2002; Marinopoulos and Stavridou, 2002) and conceptual change instruction (Alparslan *et al*, 2003). Moreover, science educators have also proposed that the integration of multiple teaching strategies could promote students' conceptual learning and knowledge construction in biological classrooms (e.g. Bean *et al*, 2001; Odom and Kelly, 2001).

In addition, White and Gunstone (1992) have proposed the POE (Prediction-Observation-Explanation) procedure as an efficient teaching strategy. The POE strategy involves students predicting the result of a demonstration and discussing the reasons for their prediction, observing the demonstration and finally explaining the discrepancies between their predictions and observations (Kearney *et al*, 2001). It may expose learners' prior knowledge for instructors, allow students to interpret their new observations of the world around them, and then offer more opportunities to share and negotiate their own personal interpretations.

The use of POE strategy, clearly, is consistent with the theory of constructivism, which highlights the importance of prior

knowledge and the construction of interpretations. In the past, the POE strategy had widely been used for physics education at secondary and high school level as a tool for teaching and assessment (for further details about the POE strategy, see White and Gunstone, 1992; Kearney *et al*, 2001; Palmer, 1995). Palmer (1995) also argued that POE could be a suitable technique for primary science. In sum, the POE strategy is regarded as a constructivist-oriented learning strategy to promote learners' conceptual learning (White and Gunstone, 1992; Liew, 1995). Consequently, it was combined with the small group cooperative learning activities and employed to promote learners' biological learning outcomes in this study.

Current practice in science education encourages the use of multiple ways to assess learners' learning outcomes. Although traditional-oriented assessment methods, such as multiple choice questions (e.g. Marinopoulos and Stavridou, 2002; Soyibo and Evans, 2002), two-tier multiple-choice test (e.g. Odom and Kelly, 2001; Alparslan *et al*, 2003; Christianson and Fisher, 1999), matching tests (Bean *et al*, 2001) and short essay questions (Bean *et al*, 2001), were widely used to assess students' learning outcomes in biological education, the measurement of learners' cognitive structures can be one of another important indicators in assessing what learners know.

Educators and cognitive scientists have tried to represent pre-acquired knowledge in terms of 'cognitive structure' (Pines, 1985; West *et al*, 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, biological educators can understand what learners have acquired. Therefore, students' cognitive structures were used as an assessment outcome variable in this study.

However, many methods of representing individual cognitive structures have been proposed, such as word association, tree construction, concept map and flow map. Tsai and Huang (2002) summarised three major aspects in the description of cognitive structures: the concepts or ideas contained; the connections between concepts; and the mode of information processing used in organising concepts. Based upon this review, the flow map (described in detail later) may be the most useful method to represent learners' cognitive structures. Anderson and Demetrius (1993) also argued that the flow-map representation required minimal intervention by the interviewer and low inference for its construction, providing a convenient diagram of the sequential and multi-relation thought patterns expressed by the respondent, and argued it was a useful method to probe learners' cognitive structures. The use of the flow map method also concurs with current neuroscience models about human cognition and information processing (Anderson, 1997). Therefore, the flow map method was used as a way to probe students' cognitive structures in this study.

Furthermore, the effects of the constructivist-oriented instruction or teaching strategies on high school or college students' learning outcomes have been widely evaluated (e.g. Odom and Kelly, 2001; Alparslan *et al*, 2003; Schmid and Telard, 1990; Christianson and Fisher, 1999; Mintzes, 2001), but few studies on elementary school students were conducted. Therefore, this study was conducted to explore the effects of the constructivist-oriented instruction on a group of Taiwanese fifth graders' cognitive structures about biological reproduction. In addition, such effects on different science achievers were also investigated.

Method

Subjects and science achievement grouping

The subjects of this study came 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 instruction group. These two groups did not show statistical differences in science academic achievement, preferences and perceptions of science learning environments before the study ($p > 0.05$). These two groups were taught by their usual science teachers, both male teachers with two years of science teaching experience.

Moreover, students' fourth grade science test scores were used to categorise students' science achievement in this study. The score average for all participant students was used to divide the students in each class into two subgroups. One was for high achievers, while the other was for low achievers. The high achiever subgroup in the constructivist-oriented instruction group included 17 students, while that in the traditional group included 19 students; the low achiever subgroup in the constructivist-oriented instruction group included 18 students, while that in the traditional group included 15 students. There was no significant difference in the science achievement score for these two high-achiever subgroups between constructivist and traditional groups. Similarly, no significant difference was found between the two low-achiever subgroups.

Description of the lessons

According to the National Standards of Elementary Science Education in Taiwan, the instruction unit on biological reproduction for fifth graders should take nine 40-minute class periods. Consequently, the students in this study received relevant instruction about biological reproduction for three successive weeks (three periods per week). The first two weeks covered different methods of plant reproduction. In the final week, different methods for animal reproduction (i.e. viviparity, oviparity and ovoviviparity) were introduced. The lecture and textbook-based method was used in the traditional group, while the constructivist-oriented instruction conducted in this study was developed by combining the POE strategy and small group cooperative learning activities. For example, in the first two weeks, students in the constructivist group were individually asked to predict (or think about) the methods of plant reproduction and write them down, and their ideas were discussed in small groups (each group contained five or six students). By watching videotapes, students could observe the reproduction of plants. Then in small groups, the students were assigned to reproduce plants, observe their reproduction, and gather information about plant reproduction by teamwork. Finally, each group reported their observations and explained the difference between their initial prediction and the observation about plant reproduction.

The constructivist-oriented instruction in this study highlighted the significance of prior knowledge and allowed learners to observe phenomena around them, share and discuss their interpretations, negotiate meanings, and actively construct biological knowledge. Compared with the traditional teaching group in this study, these instructional activities could be regarded as relatively constructivist-oriented.

Data collection, analysis and the flow map method

Students were interviewed to explore their cognitive structures about biological reproduction. To probe learners' cognitive structures about biological reproduction, non-directive questions asked by researchers were as follows:

1. Please tell me what are the main ideas or ways of biological reproduction.
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?

All of the interviews above were tape-recorded. Then, each student's interview narrative was transcribed into the format of a 'flow map.'

Figure 1 shows a constructivist-oriented instruction group student's flow map after the unit of 'biological reproduction.' The basic 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.

There are two types of arrows used in the flow map. The linear or serial arrows show the direct flow of the learner's narrative, while the recurrent arrows show the revisited ideas among the statements displayed in the flow map. For example, the student's narrative mapped in Figure 1 shows a sequential pattern beginning with plant reproduction and progressing to the methods of animal reproduction. The student also gave some concrete examples of plant reproduction, such as beans, roses. Recurrent arrows are inserted that link revisited ideas to the earliest step where the related idea first occurred. Statement 2, for example, 'beans use their seeds for reproduction' includes one revisited idea, 'seeds for reproduction.' Thus, Statement 2 has one recurrent arrow drawn back to Statement 1, i.e. plants can use seeds, stems or roots for reproduction (for further details about the flow map method, see Anderson and Demetrius, 1993; Tsai, 2001; Tsai and Huang, 2001). Figure 2 shows another student's flow map, with similar rules for diagramming the interview narrative.

Through using this method, 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 biological reproduction for the two participating classes. The number of linear linkages could be viewed as the **extent** of concepts or ideas within the student's cognitive structure, whereas the number of recurrent linkages

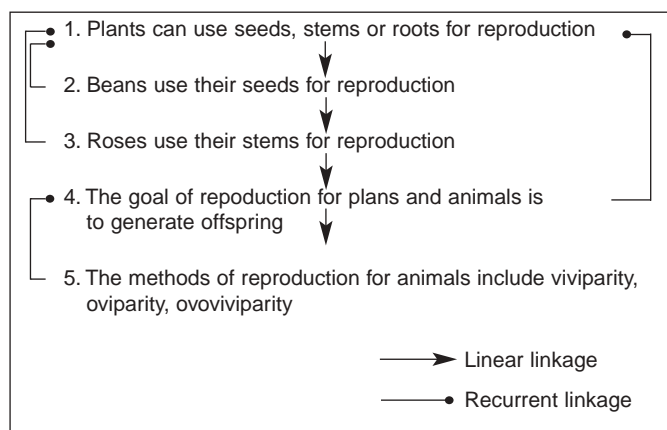


Figure 1. A low achiever's flow map from the constructivist-oriented instruction group

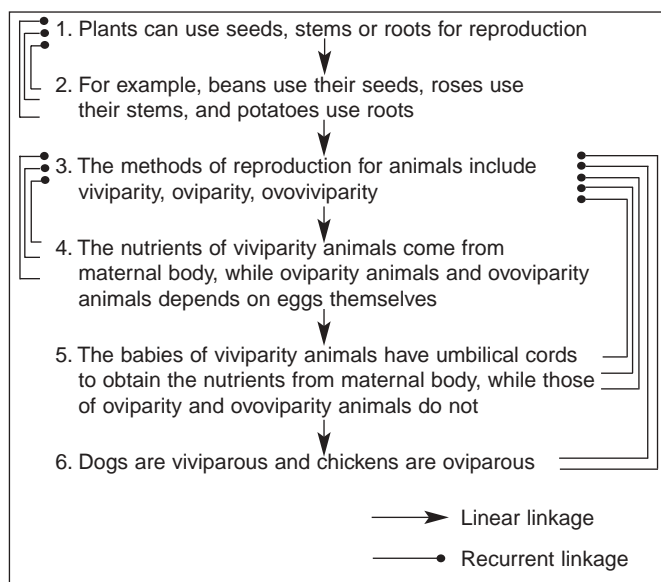


Figure 2. A high achiever's flow map from the constructivist-oriented instruction group

could be viewed as an indicator of its **richness**. For example, there are six linear linkages in Figure 2, and five in Figure 1; in Figure 2 there are 11 recurrent linkages, but only four in Figure 1.

In addition, the information processing modes shown in the flow maps were investigated through a series of content analyses. To acquire a deeper understanding of a student's usage among different modes of processing knowledge about biological reproduction, each of the student's statements shown in the flow maps was categorised into one of the following four levels of information processing modes (adapted from Tsai and Huang, 2001):

1. *Defining*: Providing a definition of a concept or a scientific term, e.g. 'ovoviviparity indicates animals that lay eggs that hatch inside the mother's body'.
2. *Describing*: Depicting a phenomenon or a fact, e.g. 'roses use their stems for reproduction'.
3. *Comparing*: Stating the relationships between (or among) subjects, things, or methods, e.g. 'compared to other methods, oviparity could generate more offspring at one time'.
4. *Inferring or Explaining*: Describing what will happen under certain conditions (e.g. 'if the pollen deposits onto a pistil, it may generate seeds'), or offering an account to justify the causality of two facts or events, (e.g. 'since viviparity in mammals is associated with parental care, it does not need a large number of offspring to increase the reproductive rate').

According to Tsai and Huang (2001), the fourth category of information processing modes (i.e. inferring or explaining) was viewed as the high-order information processing mode in this study.

The statements in each flow map were categorised (for instance, Statement 2 in Figure 2, 'for example, beans use their seeds, roses use their stems, potatoes use roots, and so on', was coded within the 'describing' category. Statement 4 in Figure 2, 'The nutrient of viviparity animals come from maternal body, while oviparity animals and ovoviviparty animals depends on eggs themselves', was coded within the 'comparing' category). The frequencies of the four-level information processing modes used by the learner were then counted. Students who frequently used higher-order modes of information processing (e.g. 'inferring or explaining') were viewed as having better strategies for organising information during recall.

After students' interview narratives were transcribed into flow maps, the reliability of flow map diagramming was determined by asking a second independent researcher to draw a subset of students' narratives. In this study, the inter-coder agreement for sequential linkages was 0.91, and for recurrent linkages was 0.88 (for the details of calculation of the reliability coefficient, please refer to Anderson and Demetrius, 1993). 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, an inter-coder reliability of 0.92 was obtained for the content analysis of information-processing modes, indicating that the two researchers coded 92% of the students' ideas into the same category of information processing modes. Therefore, the content analysis of information processing modes in this study was viewed as sufficiently reliable.

Results

In this study, a series of t-test analyses were conducted to examine the difference in students' cognitive structures between constructivist and traditional groups. Table 1 presents the data on students' cognitive structure outcomes and their information processing modes gathered from the interviews. The results in Table 1 show that these two groups of students had significant differences in terms of 'linear linkages' and 'recurrent linkages' ($p < 0.01$). The students in the constructivist-oriented instruction group attained better learning outcomes about biological reproduction after instruction, both in terms of the extent of concepts and the richness within their cognitive structures.

It was also found that both the *Cohen's d* values of 'linear linkages' and 'recurrent linkages' were larger than 0.8; that is, the practical significance of both 'linear linkages' and 'recurrent linkages' was large (Cohen, 1988). This might imply that students would acquire more concepts and develop more integrated cognitive structures after the constructivist-oriented instruction than the traditional instruction did. The well-organised cognitive structures might help learners store more information in their long-term memory.

Moreover, the results in Table 1 also revealed that these two groups of students had significant differences in their usage of two modes of information processing, namely, 'describing' and 'inferring or explaining' ($p < 0.01$); however, no significant difference was found in their usage of the other modes of information processing, 'defining' and 'comparing'. The students in the constructivist-oriented instruction group tended to store more concepts or ideas in describing the related scientific information about biological reproduction. Furthermore, the students in the constructivist-oriented instruction group were probably better

organised and stored their ideas in a higher-level mode of information processing, the 'inferring or explaining' modes. Both the *Cohen's d* values of 'describing' and 'inferring or explaining' were larger than 0.8. In other words, the practical significance of both the usage of 'describing' and 'inferring or explaining' was large. The constructivist-oriented instruction is likely to have facilitated the connections between new conceptions and pre-existing knowledge within learners' cognitive structures and promote the usage of higher-level information processing modes.

The difference in high achievers' cognitive structure outcomes between constructivist-oriented and traditional groups was also explored by conducting similar t-test analyses. Table 2 presents the data on the high achievers' cognitive structure outcomes and their information-processing modes between two instructional groups. It showed that there were significant differences in terms of 'linear linkages' and 'recurrent linkages' between these two high achiever subgroups ($p < 0.01$). Moreover, both of the *Cohen's d* values of 'linear linkages' and 'recurrent linkages' were far larger than 0.8 (i.e. the practical significance of both 'linear linkages' and 'recurrent linkages' was large). These results indicated that the high achievers in the constructivist-oriented instruction group displayed larger and more integrated cognitive structures than their opposite numbers in the traditional group.

It was also revealed that there were statistical differences between these two high achiever subgroups in their usage of two modes of information processing, 'describing' and 'inferring or explaining' ($p < 0.01$); however, no significant difference was found in their usage of the other two modes. Moreover, both the *Cohen's d* values of 'describing' and 'inferring or explaining' were far larger than 0.8: the practical significance of the usage of both 'describing' and 'inferring or explaining' was large. The results suggested that high achievers would benefit more from the constructivist-oriented instruction in their usage of high-order information processing modes, such as inferring and explaining.

Similarly, a series of t-tests were conducted to investigate whether the low achievers in the constructivist-oriented instruction group outperformed their peers in the traditional group on the cognitive structure outcomes. Table 3 presents the data on the low achievers' cognitive structure outcomes and their information processing modes. The results show that there was significant difference in cognitive structure outcomes both in 'linear linkages' and 'recurrent linkages' ($p < 0.05$) between these two low achiever subgroups. The practical significance of 'linear linkages' was middle ($0.5 < \textit{Cohen's d} < 0.8$), and the practical significance of 'recurrent linkages' was large (*Cohen's d* > 0.8). In other words, constructivist-oriented instruction helped low achievers develop more extended and connected cognitive structures than traditional teaching.

Table 1. Students' cognitive structure outcomes and information processing modes between groups

	Constructivist-oriented (n=35)		Traditional (n=34)		t	Cohen's d ¹
	Mean	SD	Mean	SD		
Linear linkages	9.23	4.19	5.38	2.80	4.50**	1.11
Recurrent linkages	8.20	5.32	3.85	2.58	4.34**	1.04
Defining	2.49	1.67	2.44	1.86	0.11	-
Describing	4.83	2.93	2.15	2.12	4.35**	1.05
Comparing	0.94	0.97	0.65	0.95	1.28	-
Inferring or Explaining	0.63	0.94	0.03	0.17	3.70**	0.92

¹ 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.

* $p < 0.05$, ** $p < 0.01$

Table 2. High achievers' cognitive structure outcomes and information processing modes between groups

	Constructivist-oriented (n=19)		Traditional (n=17)		t	Cohen's d ¹
	Mean	SD	Mean	SD		
Linear linkages	11.24	3.05	5.95	2.95	5.28**	1.76
Recurrent linkages	10.65	5.20	4.74	2.75	4.33**	1.42
Defining	3.18	1.47	2.47	1.58	1.38	-
Describing	5.53	2.53	2.21	2.30	4.13**	1.37
Comparing	1.18	1.13	1.11	1.05	0.20	-
Inferring or Explaining	1.12	1.11	0.05	0.23	3.88**	1.33

¹ 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.

* p<0.05, ** p<0.01

The results in Table 3 further reveal that these two subgroups of students had significant differences in their usage of two modes of information processing, namely 'describing' (p<0.05) and 'comparing' (p<0.01); but no significant difference was found in their usage of the other modes of information processing, 'defining' and 'inferring or explaining'. Furthermore, both the Cohen's d values of 'describing' and 'comparing' were larger than 0.8. In other words, the practical significance of both the usage of 'describing' and 'comparing' were large.

The results indicated that low achievers also benefited from the constructivist-oriented instruction in their usage of information processing modes, but in somewhat different ways from high achievers. Low achievers in the constructivist group may construct more ideas in the mode of 'comparing' than those in the traditional group, but high achievers in the constructivist group may utilise more 'inferring or explaining' mode of information processing.

Based upon the flow map analysis of fifth grader narratives, this study explored the effects of the constructivist-oriented instruction on students' cognitive structures about biological reproduction. In this study, 'inferring or explaining' was viewed as the high-order information processing mode. Therefore, the results of this study can be summarised as shown in Table 4.

Table 4 shows that students in the constructivist-oriented instruction group, in general, attained significantly better learning outcomes in the extent, and the integration, of their cognitive structures and the usage of high-order information processing modes; however, low achievers in the constructivist-oriented instruction group did not significantly outperform those in the traditional group in their usage of high-order information-processing modes.

A series of ANOVA test analyses were also conducted to explore the possible interactions of students' academic achievements and the instruction method. The results revealed that students' academic achievement and the instruction method

only showed significant interaction effects on the usage of the 'inferring or explaining' information processing mode (F=9.671, p<0.05). Through a series of Scheffe tests, it was found that there were significant differences between high achievers and low achievers in the traditional instruction group. However, no significant difference was found between high achievers and low achievers in the constructivist-oriented instruction group. Again, the students of the two high-achiever subgroups displayed significant differences in their usage of high-order information processing modes (i.e. inferring or explaining), while the students of two low-achiever subgroups did not. This indicated that high achievers benefited more from the constructivist-oriented instructional activities, especially, in their usage of high-order information processing mode.

Discussion and implications

Driver *et al* (1994) have argued that the learning of science is a process of knowledge construction involving both individual and social perspectives. The constructivist-oriented instruction could provide more opportunities for learners to construct their own personal interpretations of the world around them, share their ideas, negotiate with others and construct their own meaning of biological knowledge. The findings of this study show that constructivist-oriented instruction could promote students' performance in biological learning in the light of cognitive structure outcomes.

Bischoff and Anderson (2001) have argued that sufficient concepts or ideas are necessary in order to precede and promote the development of more complex ideational patterns in the learner's cognitive structure. Constructivist-oriented instruction, in the present study, helped students develop more extended knowledge frameworks about biological reproduction. These extended knowledge structures, probably serving as scaffolding, may also facilitate the construction of more integrated cognitive structures. Therefore, the finding in this study is consistent with the argument proposed by Bischoff and Anderson (2001).

Table 3. Low achievers' cognitive structure outcomes and information processing modes between groups

	Constructivist-oriented (n=15)		Traditional (n=18)		t	Cohen's d ¹
	Mean	SD	Mean	SD		
Linear linkages	7.33	4.30	4.67	2.50	2.12*	0.77
Recurrent linkages	5.89	4.42	2.73	1.91	2.74*	0.93
Defining	1.83	1.62	2.40	2.23	-0.85	-
Describing	4.17	3.19	2.07	1.94	2.23*	0.80
Comparing	0.72	0.75	0.07	0.26	3.46**	1.16
Inferring or Explaining	0.17	0.38	0.00	0.00	1.84	-

¹ 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.

* p<0.05, ** p<0.01

Table 4. A summary of cognitive structure outcomes and information processing modes among different subjects

	Constructivist group v.s. Traditional group (total)	Constructivist v.s. Traditional high achievers subgroup	Constructivist v.s. Traditional low achievers subgroup
Extent of cognitive structure	**	**	*
Integration of cognitive structure	**	**	**
High-order information processing mode	**	**	-

* Cohen's *d* > 0.5, ** Cohen's *d* > 0.8

Biology teachers should encourage and promote learners' use of higher-order information processing modes through which they organise and store their biological ideas or concepts. The results in this study reveal that high achievers in the constructivist-oriented instruction group attained better usage of high-order information processing modes than their peers in the traditional group. This was probably due to the fact that the learners (especially higher achievers) in the constructivist biological 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 to shape their concepts or ideas. It is also argued that low (or middle, such as 'comparing') order cognitive operations may act as precursors to the development of high order operations and may be increasingly replaced by them (Bischoff and Anderson, 2001). If the treatment in this study could last longer, the lower achievers in the constructivist group might display more high-order information processing. So, further exploration is suggested to investigate the progression of learners' information processing, particularly by documenting low achievers' ways of constructing knowledge. Clearly, such research requires more time and instructional units to obtain reliable findings. Moreover, the use of higher-level information processing strategies and the increase in networking connections among existing concepts may mutually reinforce one another (Tsai and Huang 2001). The findings of the present study may indicate that constructivist-oriented instruction could also help learners to use more generalised or advanced forms of knowledge (e.g. explaining) to express their understanding of the biology, as their cognitive structures become more elaborate.

This study also examined the applicability of the POE strategy in primary school biology classes. Tsai (2001) has suggested that the use of POE instructional activities is useful for enhancing students' information processing levels. The findings in this study have supported the proposal that the POE is a useful instructional strategy to promote not only students' cognitive structure outcomes but also their usage of high-order information processing modes, which concurs with Tsai's (2001) suggestion.

In conclusion, this study showed some evidence that students in the constructivist-oriented instruction group, in general, attained significantly better biological learning outcomes in the light of the extent and integration of their cognitive structures, and the use of high-order information processing modes. The findings of this study also suggest that instructors can utilise constructivist-oriented instructional activities, such as the POE strategy and cooperative learning activities, to enhance students' conceptual learning and knowledge construction in primary school biology classes.

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