International Journal of Science Education
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsed20

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Published online: 16 Jul 2010.

INT. J. SCI. EDUC., 2000, VOL. 22, NO. 10, 1099-1115

The effects of STS-oriented instruction on female tenth graders' cognitive structure outcomes and the role of student scientific epistemological beliefs

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The major purpose of this study was to investigate the effects of STS (Science-Technology-Society) instruction on a group of Taiwanese female tenth graders' cognitive structure outcomes. This study further examined the role of student scientific epistemological beliefs on such effects. One hundred and one female tenth graders were assigned to either a STS-oriented instruction group or a traditional teaching group and then this study conducted a eight-month research treatment. Students' interview details, analysed through a 'flow map' method, indicated that STS group students performed better in terms of the extent, richness and connection of cognitive structure outcomes than did traditional group students. Further analyses suggested that STS instruction was especially beneficial to students having epistemological views more oriented to constructivist views of science, particularly in the beginning stage of STS instruction. This implies that learners' scientific epistemological beliefs may be an important factor mediating the implementation of STS-oriented instruction.

Introduction

Recently, educators have suggested that science education should give pre-eminence to teaching *about* science rather than teaching *in* science, or teaching science (Osborne *et al.* 1998, Duschl 1990, Duschl *et al.* 1990). That is, science instruction should address, for example, the following questions: what do scientists do? How does scientific knowledge develop? How does science come to achieve such knowledge? What is the impact of science and technology on society, and conversely, how do human values and concerns influence the practice of science? As proposed by Tsai (1998a), Science-Technology-Society (STS) instruction is a potential means to explicate these epistemological-oriented issues. A STS instructional approach has been proposed as a way of improving science education since 1980. Currently, it remains an international trend in reforming the practice of science education (for example, Bybee 1991a, Solomon 1993, Solomon and Aikenhead 1994). Yager and Tamir (1993) have concluded that STS instruction has positive impacts on students' conceptual understanding, process skill, attitude and creativity in science. They, however, urge educators to continue exploring the following research topics: (1) developing more evaluation materials that provide ways of indicating student improvement through STS instruction, and (2) examining the effects of STS instruction on female students. This study, an attempt to study the effects of STS instruction on *female* tenth graders' cognitive structure

International Journal of Science Education ISSN 0950-0693 print/ISSN 1464-5289 online
http://www.tandf.co.uk/journals

outcomes, was conducted to address the research issues above. STS learning environments are rich in multi-disciplinary perspectives and encourage diverse and creative thought processes. This suggests that more creative means of assessing educational outcomes are needed when evaluating STS learning. Cheek noted this and concluded that 'limiting assessment to a set of pencil and paper, multiple-choice type items too narrowly constricts the scope of STS education and fails to capture valuable learning by students' (1992: 66). There is no prior STS-related study using students' cognitive structures as an assessment outcome variable.

This study could also be viewed as another way of testing the practice of constructivism in science education, because the features of STS instruction are congruent with those elaborated as examples of constructivist practices (Yager 1995). For example, both STS instruction and so-called 'constructivist teaching' emphasize student autonomy, encourage students to interact with each other and with the teacher, and explore scientific concepts in the context of human experiences.

Furthermore, as previously suggested, STS instruction could address some epistemological-oriented issues about science for students. Prior research (for example, Tsai 1998a, 1999a) reveals that, even junior high school students have their own Scientific Epistemological Beliefs (SEBs) when acquiring scientific knowledge. It is, hence, plausible to anticipate that students' SEBs may mediate the implementation of STS instruction. Yager and Lutz (1995) also implied that there was a linkage between students' views about science and the use of STS instruction. Theorists of 'conceptual change' usually view SEBs as an essential feature in one's conceptual ecology (Posner *et al.* 1982, Strike and Posner 1985, 1992). These beliefs, then, may highly affect subsequent learning. Research evidence also shows that students having SEBs more oriented to constructivist views of science (as opposed to empiricist views of science) tend to employ more meaningful learning modes, deeper information processing strategies and prefer a more open-ended and integrated approach to instruction (Edmondson and Novak 1993, Hammer 1994, 1995, Songer and Linn 1991, Tsai 1996, 1997, 1998a, 1998b, 1999a, 2000). Consequently, this study explored in greater depth the role of student SEBs in STS instruction. There is no past research directly addressing this research topic.

In sum, this study was conducted to examine the effects of STS-oriented instruction (versus traditional teaching strategy) on a group of Taiwanese female tenth graders' cognitive structure outcomes. Moreover, this study investigated the possible interaction between students' SEBs and the use of STS-oriented instruction in determining students' cognitive structure outcomes. To state more specifically, this study, conducted through a long-term (eight months) experimental research design, evaluated the following two hypotheses:

(1) Students in a STS group, on average, will have greater gains in organization of knowledge as measured by cognitive structure variables than students in traditional instruction.
(2) Students holding SEBs more oriented to constructivist views of science will perform better (in terms of cognitive structure outcomes) with STS-oriented instruction, while students having SEBs more aligned with empiricism will show better cognitive structure outcomes with tradi-

tional teaching strategies. That is, there is an interaction between students' SEBs and the instructional approach.

Windschitl and Andre (1998), who explored a similar set of research issues, examined the merits of computer simulations (as a constructivist-oriented instructional treatment) and the role of student epistemological beliefs on the efficacy of this educational strategy. However, Windschitl and Andre (1998) employed traditional-oriented assessment method (for example, multiple choice post-test) as a major outcome variable, and they investigated the role of student epistemological beliefs (i.e., beliefs about the nature of knowledge and learning in general), but not *scientific* epistemological beliefs, in constructivist-oriented instruction. Also, the subjects in their research were college students, while the subjects in the present study were high school female students. Therefore, the research purposes and approach in the present study are very different from those of their study. Both studies, however, could be viewed as attempts to evaluate the effectiveness of constructivist-oriented instruction in improving science learning.

Method

The sample and the research treatment (STS-oriented instruction) in this study are exactly the same as those reported in a previous paper (Tsai 1999b). Tsai's (1999b) study examined how STS instruction may play a role in respect of student SEBs. Through analysing student questionnaire responses and interview data, the study documented student possible SEB change resulting from STS instruction. The present study, however, addresses the effects of STS instruction on students' cognitive structure outcomes and it further explores the possible interaction between student SEBs and instructional approaches (STS versus traditional teaching) in determining student cognitive structure outcomes. In order to avoid redundant overlap between these two papers, the description of the sample, the research treatment and the instrument of assessing student SEBs is briefly presented in this paper.

Sample

The subjects of this study came from two female (single-sex) tenth-grade classes of a high school of Taipei City, a total of one hundred and one female students. These students had been selectively admitted based on their performance on a Joint High School Examination in the beginning of this study. Through taking the Examination, about 400 female tenth graders were admitted to the high school every year, and they were randomly assigned into eight classes. Since this study was conducted about one month after the class assignment above, the students in these two classes could be viewed as being randomly assigned. In addition to randomized assignment, a cross-class test (traditional-oriented basic scientific knowledge test) administered by the school immediately before this study also indicated that there was no significant difference in science achievement between these two classes (n.s., $p \gg .05$). Then, one class was assigned to a traditional group (a total of 49 students) and the other to a STS group (52 students).

Table 1. The comparisons of traditional group instruction and STS group instruction in this study

	Traditional group	*STS group*
Role of the teacher	Information provider Course controller	Facilitator of student learning process Leader of whole-class discussion Model of scientific thinking
Instructional content	Fact-based scientific knowledge Tutorial problems	The interplay among science, technology and society Science-related issues in society or local contexts
Content sources	Taiwan's nation-wide textbook	Newspapers, World Wide Web, history of science, community resources, science-related magazines and textbooks
Instructional method	Textbook reading Almost one-way lecturing Tutorial problem solving exercises	Inquiry-based exploration Cooperative group learning Role-playing activities Issue-based debating and discussion

Treatment (STS versus traditional instruction)

This study used an experimental approach to test the research hypotheses described earlier. Table 1 shows the major differences between traditional group instruction and STS group instruction used in this study. For example, STS instruction utilized a variety of instructional resources (for example, newspapers, World Wide Web, lessons from the history of science or other community resources), and it addressed the interaction between science, technology and society, presented scientific concepts in the context of human experiences, and discussed current science-related issues and problems in society or in the local context (for example, energy depletion, pollution explosion). On the other hand, the traditional group students mostly followed the fact-based content provided by the nation-wide textbook. The students in the STS group as expected may have spent more time in some after-class peer discussion; however, the in-class instructional time was the same for both groups (four 50-minute periods per week).

The approach of implementing STS instruction in this study was infusing STS materials and activities into an existing course, in this case the 'fundamental physical science' course, regularly taught at Taiwanese tenth grade. The author, the STS group teacher and some STS researchers, based on the Taiwan's nation-wide curriculum, cooperatively developed STS instructional materials for this study. Both STS and traditional groups followed the same teaching sequence in presenting major science concepts since there were cross-class achievement tests that all students must take almost every month within the school. The control (traditional group) and treatment (STS group) classes each lasted about eight months, a very long period of research treatment not frequently found in science education research.

Cognitive structure outcomes

There were the following three cognitive structure assessments in this study:

(1) exploring students' ideas of 'light', conducted in the second month of the treatment;
(2) assessing students' ideas of 'electricity', conducted in the fifth month of the treatment; and
(3) eliciting students' ideas of 'nuclear energy', conducted in the final month of the treatment.

The content sequence of these assessments corresponded to that of nation-wide curriculum. For each assessment, about 20 students from each group were randomly selected. Through interviewing these students (using a standardized set of questions without providing any directive suggestions, please refer to Anderson and Demetrius 1993, Tsai, 1998b), they were asked to freely recall or reconstruct what they had learned from the instruction. By such an interview-recall method, coupled with a 'meta-listening' technique (i.e., asking each subject to listen to a tape-reply of her *immediate* prior elicited recall and possibly to modify her original ideas, see Tsai 1998b), every selected student's interview narrative, which was fully recorded by audio tape, was further analysed by a 'flow map' method (Anderson and Demetrius, 1993). A flow map is constructed by diagramming the respondent's verbalization of thought as it unfolds, and it is a convenient way to display the sequential and complex or cross-linkage thought patterns expressed by the respondent. This way of analysing students' cognitive structures has been employed in some other studies (for example, Anderson *et al.* 1998, Bischoff and Anderson 1998, Demetrius 1998), and these studies conclude that the 'flow map' analysis is a useful and valid method of representing students' conceptual knowledge frameworks in science.

Basically, the flow map is assembled by entering the ideas in sequence as they are uttered by the subject and these ideas are linked by a connecting arrow (both serially and then as cross-relations among revisited ideas). Figure 1 displays a sample flow map analysed in this study. The student recalled what she had learned about 'light' from the instruction, shown as a total of 13 ideas in sequence. The final four ideas were added by the student after she listened to her prior elicited recall; that is, these ideas were generated as a result of the 'meta-listening' period. As required by the flow map method, the researchers inserted recurrent arrows that link new ideas to the earliest step where the related idea (i.e., revisited idea) occurred. Statement 8, for example, 'the refraction of prism, showing seven colors of light, is an example of dispersion phenomena', includes two major revisited ideas, that is, 'refraction' and 'dispersion phenomena'. Consequently, statement 8 has two recurrent arrows that point back to statement 4 (the earliest step stating about 'refraction') and to statement 7 (the earliest step stating about 'dispersion phenomena'). Moreover, students' misconceptions (if any) were also included for this part of analysis, because they still represented part of the respondent's cognitive structures. However, the student's ideas of figure 1 did not contain any scientific misconception.

Students' ideational networks generated from the flow map method were used as the evidence representing their cognitive structures. By employing the flow-

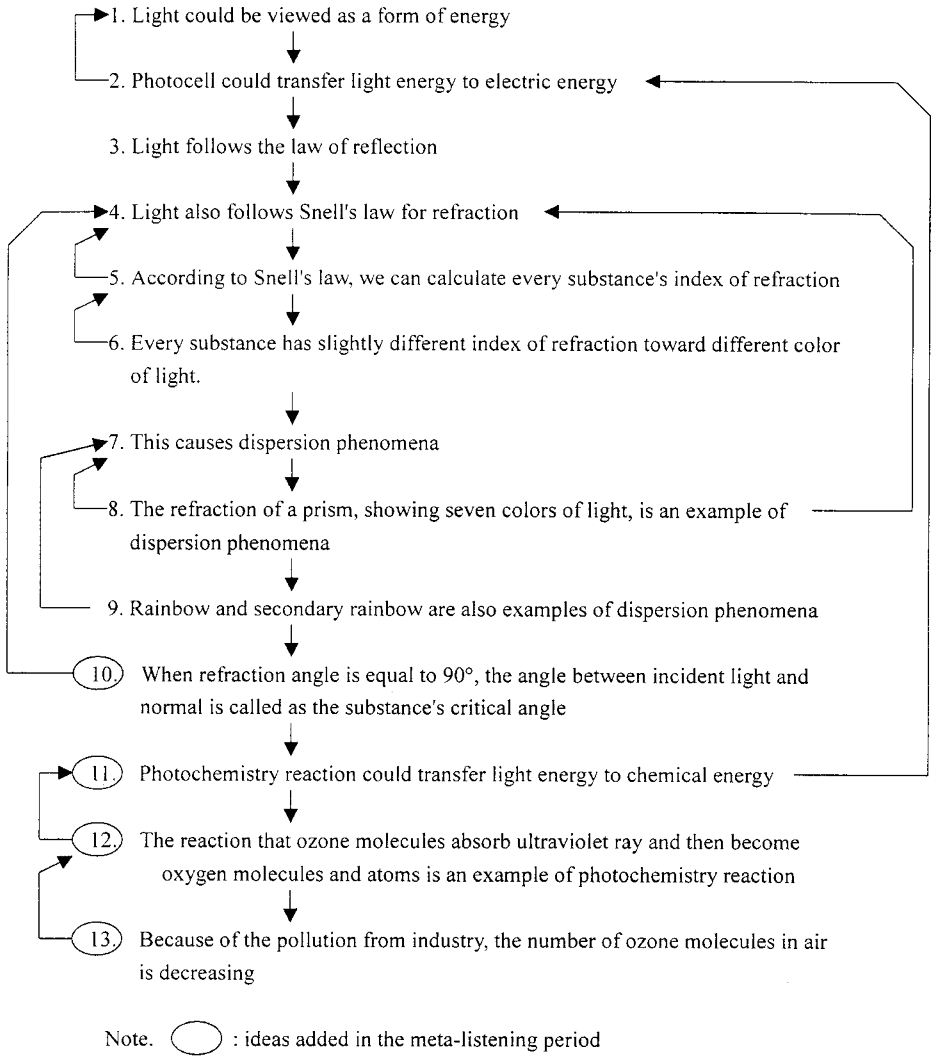

Figure 1. A flow map based on a STS subject's recalled narrative about 'light'. The final four ideas were added by the student after she listened to her ideas presented in the first part of the interview (i.e., replaying the audiotape of her ideational discourse from statement 1 to statement 9).

map method, this study yielded the following four major cognitive structure outcome variables:

(1) size or extent: linear linkages or number of ideas (for example, 13 in figure 1);
(2) richness: number of recurrent or cross linkages (for example, 10 in figure 1);
(3) connection: proportion of recurrent linkages, showing the association density of the cognitive structure, equal to number of cross-linkages

divided by (number of ideas + number of recurrent or cross-linkages) (for example, $10/(13+10)$, 0.43 in figure 1); and

(4) correctness: number of misconceptions (for example, 0 in figure 1). Consequently, a lower score on this variable indicates a higher precision of the ideational networks.

In order to examine the reliability of the flow maps used in this study, a second independent researcher was asked to analyse 20 randomly selected examples of narrative data (among almost 120 narrative data for three assessments). The inter-coder agreement for sequential statements was 0.91 and for cross linkages was 0.87. These agreement coefficients were similar to those reported in prior studies (Anderson and Demetrius 1993, Tsai 1998b).

Instrument assessing student scientific epistemological beliefs

A Chinese-version of Pomeroy's (1993) questionnaire was administered to assess students' SEBs. The questionnaire consists of bipolar agree-disagree statements on a 5-1 Likert scale. The scores of the questionnaire could be viewed as representing a one-dimensional assessment of students' SEBs; namely, a continuum from empiricist to constructivist perspectives.[1] The empiricist position assumes that scientific knowledge is a discovery of an objective reality external to ourselves and it is discovered by observing, experimenting or application of a universal scientific method. The position also implies that evidence in science accumulated carefully will produce infallible knowledge. The constructivist views of science emphasize the theory-laden quality of scientific exploration and the role of conceptual change in progressive evolution of scientific understanding. These views also support that scientific knowledge should be regarded as an invented reality, which is also constructed through the use of agreed-upon paradigms, acceptable forms of evidence, social negotiations in reaching conclusions, as well as technological and contextual impacts as recognized by participating scientists (Tsai 1998c). This study used Pomery's items that represent a range of viewpoints including at one pole of 'traditional views of science' (empiricist views: for example, scientists rigorously attempt to eliminate human perspective from observation) to the other pole of 'nontraditional views of science' (constructivist views: for example, non-sequential thinking (i.e. taking conceptual leaps) is characteristic of many scientists). The final questionnaire consisted of 17 items.[2] Pomeroy (1993) reported that the reliability for these two parts was moderately high (Cronbach's $\alpha = 0.651$, and 0.591, respectively). The same coefficients calculated from this study were 0.703 and 0.662 respectively for these two parts.

As this study assumed that students' SEBs could be represented by a continuum from empiricist to constructivist perspectives, it investigated such a one-dimensional assessment of students' SEBs. Hence, students' questionnaire responses were scored as follows to represent their SEBs. For the constructivist perspective items, a 'strongly agree' response was assigned a score of 5 and a 'strongly disagree' response was assigned a score of 1, while items representing an empiricist view were scored in a reverse manner. A prior study that compared student questionnaire results and interview details with twenty 14-year-old students (Tsai 1998a) supported that such a scoring method, in general, could differentiate student SEB orientation. This scoring manner was also employed in some other studies about student SEBs (for example, Tsai 1997, 1998b, 1999a, 1999b, 2000). By this way, students having strong beliefs about the constructivist views would have higher average scores on the questionnaire. On the other hand, students with empiricist-aligned SEBs would have lower average scores.

In this study, students' SEBs were considered as a changing variable across the treatment time.[3] Thus, a SEB survey (i.e., Pomeroy's questionnaire) was administered about two to three weeks before each cognitive structure assessment. (The first SEB survey was conducted immediately before the research treatment, and there was no significant score difference between these two groups in the first SEB survey). When examining the interaction between instructional groups and student SEBs in determining cognitive structure outcomes (i.e., the second hypothesis proposed earlier), this study used corresponding cognitive structure and SEB results.

Findings

Hypothesis 1: students in a STS group will have greater gains in cognitive structure outcomes than students in a traditional group

Table 2 provides students' performance on three cognitive structure assessments based on interview data analysed through the flow map method. This study compared the extent, richness, the connection and correctness (i.e., misconception) of cognitive structure outcomes between students of the traditional group and those of the STS group. Through using t-test analyses, students in the STS group displayed a larger and richer store of knowledge networks (i.e., extent and richness) than students in traditional group (both $p < 0.05$) for the first cognitive structure assessment. For the second assessment, although students in the STS group did not recall significantly more ideas than their counterparts, their ideational networks were richer ($p < 0.05$) and more integrated ($p < 0.01$). For the third assessment, conducted in the final stage of the eight-month treatment, the extent, the richness and the connection of the STS group students' cognitive structures were significantly better than those of the traditional group students ($p < 0.05$, $p < 0.01$ and $p < 0.05$, respectively). The clearly better ideational networks displayed by the STS group students in the final assessment (in three of four cognitive structure dimensions defined in this study) may have stemmed from the following: (1) 'nuclear energy' is relatively a more appropriate topic of conducting STS instructional activities (see a survey by Bybee 1991b); and (2) after a very long period of research treatment, STS instruction really had significant contribution to more diverse features of students' cognitive structure outcomes. The three assessment results, in general, indicated that students developed larger, more complex and ideationally richer schemata through STS-oriented instruction. In all assessments, the STS group students did not show significantly less misconceptions than their counterparts; however, the female students, in either group, stated very few scientifically inaccurate ideas in such recall assessments (an average of 0.30 per flow map or only 3.9% of their ideas were misconceptions). A plausible interpretation for this finding is that these female students may have been used to only state ideas that were certain to them (perhaps, due to the traditional instructional strategies they commonly received). By and large, the findings support the first research hypothesis that STS instruction did show positive impacts on these

Table 2. Cognitive structure comparisons between traditional and STS groups

	Extent (mean, SD)			*Richness (mean, SD)*			*Connection (mean, SD)*			*Misconception (mean, SD)*		
	Traditional	*STS*	*t*	*Traditional*	*STS*	*t*	*Traditional*	*STS*	*t*	*Traditional*	*STS*	*t*
First assessment[a]	7.55[2.67][d]	9.25[2.57]	−2.05*	5.15[3.01]	7.15[3.00]	−2.11*	0.37[0.13]	0.42[0.09]	−1.36	0.45[0.60]	0.35[0.59]	0.53
Second assessment[b]	6.59[2.37]	6.83[1.98]	−0.33	3.65[1.93]	5.33[2.22]	−2.39*	0.32[0.11]	0.43[0.06]	−3.50**	0.24[0.44]	0.28[0.46]	−0.28
Final assessment[c]	6.90[1.77]	8.25[2.17]	−2.15*	5.00[1.72]	6.80[2.14]	−2.93**	0.41[0.06]	0.45[0.04]	−2.06*	0.25[0.44]	0.20[0.41]	0.37

Notes: * $p < 0.05$, ** $p < 0.01$ by t-test.
a. $n = 20$ for traditional group and $n = 20$ for STS group
b. $n = 17$ for traditional group and $n = 18$ for STS group
c. $n = 20$ for traditional group and $n = 20$ for STS group
d. Value in parentheses is standard deviation

female students' cognitive structures. This conclusion also concurs with the suggestion proposed by Yager and Tamir (1993) that STS instruction is beneficial to female students.

Table 2 further shows that when compared to the findings revealed in some studies completed in the USA (for example, Bischoff and Anderson 1998), these female students seemed to recall only limited information through such a free-recall interview task, even after conducting the meta-listening stimulation (with an average of 7.6 ideas per flow map). It may come from the fact that these students, especially in the educational environments of Taiwan, were not usually encouraged to verbally express their ideas. They may be used to taking paper-and-pencil tests or they needed some suggestive hints (for example, the cues provided by options in multiple-choice questions) when reconstructing their ideas. This research views that students' performance in the recall interview is a more appropriate indicator of students' self-constructed understanding, because the assistance of directive, reward guiding, or even misleading suggestions offered by the evaluator, may perturb the natural recall of constructed knowledge offered by the respondents. The results of this study revealed that the STS students generally achieved better using such a free-recall cognitive structure assessment than students who received traditional instruction.

Hypothesis 2: there is an interaction between student SEBs and instructional approaches in determining student cognitive structure outcomes

In order to test the second research hypothesis, this study used the following three variables as predictors in regression models to predict student various cognitive structure outcomes (including the outcomes of the extent, richness, the integratedness and correctness of ideational networks shown in each cognitive structure assessment):

(1) instructional group (STS versus traditional);
(2) student SEBs; and
(3) instructional group × SEBs (i.e., instructional group multiple SEBs).

That is, this study constructed a total of twelve separate regression models to predict the students' four individual cognitive structure dimensions in combination with three interview assessments (resulting in twelve outcome variables). The predictor variables were instructional condition, SEBs and group × SEBs. For example, the first regression model used instructional group, student SEBs and group × SEBs variables to predict the extent of students' ideational networks obtained in the first assessment.[4] Tables 3-5 show the twelve regression models.

Among these twelve regression models, a statistical interaction between instructional groups and student SEBs was found in the following four regression models:

(1) Model predicting the extent of student cognitive structures in the first assessment.
(2) Model predicting the richness of student cognitive structures in the first assessment.

Table 3. Regression models testing the interaction between instructional conditions and student SEBs for the first cognitive structure assessment outcomes

Dependent variable	*Predicting variables*	*B*	*S.E.*	*û*	R^2
Extent	Group	−22.4	9.19	−4.17*	
	SEBs	−2.26	1.98	−0.20	
	Group × SEBs	8.29	3.15	4.54*	0.25
Richness	Group	−29.4	9.99	−4.75**	
	SEBs	−1.10	2.15	−0.09	
	Group × SEBs	10.7	3.43	5.11**	0.33
Connection	Group	−0.85	0.38	−3.86*	
	SEBs	−0.001	0.08	−0.003	
	Group × SEBs	0.31	0.13	4.09*	0.22
Misconceptions	Group	−2.13	2.26	−1.82	
	SEBs	−0.16	0.49	−0.07	
	Group × SEBs	0.70	0.78	1.76	0.03

Note: The R^2 value is calculated by totalling the contribution of three predicting variables.
* $p < 0.05$, ** $p < 0.01$

Table 4. Regression models testing the interaction between instructional conditions and student SEBs for the second cognitive structure assessment outcomes

Dependent vatiable	*Predicting variables*	*B*	*S.E.*	*û*	R^2
Extent	Group	−13.4	9.50	−3.17	
	SEBs	−0.87	2.12	−0.09	
	Group × SEBs	4.65	3.23	3.26	0.28
Richness	Group	−18.9	8.50	−4.29*	
	SEBs	−1.15	1.90	−0.12	
	Group × SEBs	6.98	2.89	4.72*	0.31
Connection	Group	−0.62	0.37	−3.16	
	SEBs	−0.10	0.83	−0.23	
	Group × SEBs	0.25	0.13	3.72	0.35
Misconceptions	Group	−0.32	2.04	−0.37	
	SEBs	−0.10	0.45	−0.05	
	Group × SEBs	0.12	0.69	0.42	0.004

Note: The R^2 value is calculated by totaling the contribution of three predicting variables.
* $p < 0.05$

(3) Model predicting the connection of student cognitive structures in the first assessment.
(4) Model predicting the richness of student cognitive structures in the second assessment.

Such an interaction, supporting the second research hypothesis, indicated that students holding SEBs more oriented to constructivist views of science performed better (in terms of ideational network outcomes) with STS-oriented instruction, while students having SEBs more aligned with empiricism showed better cognitive

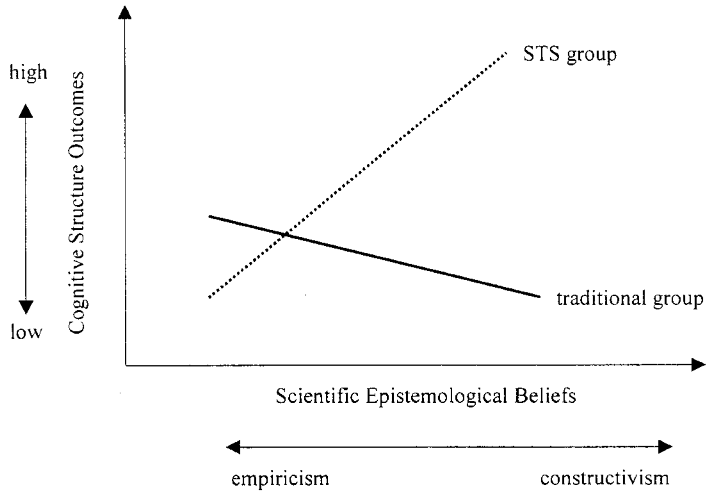

Figure 2. The interaction between the instructional condition and scientific epistemological beliefs in predicting students' cognitive structure outcomes.

Table 5. Regression models testing the interaction between instructional conditions and student SEBs for the third cognitive structure assessment outcomes

Dependent variable	*Predicting variables*	*B*	*S.E.*	*û*	R^2
Extent	Group	−14.6	8.94	−3.57	
	SEBs	0.07	1.66	0.008	
	Group × SEBs	5.22	2.97	3.91	0.21
Richness	Group	−13.32	8.68	−3.18	
	SEBs	0.53	1.61	0.06	
	Group × SEBs	4.92	2.88	3.60	0.29
Connection	Group	0.03	0.25	0.31	
	SEBs	0.05	0.05	0.23	
	Group × SEBs	−0.003	0.08	−0.07	0.15
Misconceptions	Group	0.89	2.04	1.07	
	SEBs	0.06	0.38	−0.03	
	Group × SEBs	−0.31	0.68	−1.12	0.02

Note: The R^2 value is calculated by totalling the contribution of three predicting variables.

structure outcomes with traditional teaching strategies. A situation like this could be illustrated as figure 2. However, this finding may be mainly applied to the beginning stage of implementing STS instruction, since such an interaction was almost found in the first assessment. Nevertheless, no statistical interaction in the final assessment results, and the findings revealed in table 2 (that STS group students performed better in the final assessment), may also imply that, after a long period of research treatment, STS instruction could be effective for students of various epistemological orientations toward science. In conclusion, STS instruction was probably more beneficial to students having SEBs more oriented to constructivist views of science, particularly in the beginning stage of STS instruction. Learners' SEBs were likely an important factor mediating the implementation of STS-oriented instruction. This further implies that having constructivist-oriented SEBs is an important prerequisite for the success of learning through STS instruction.

Discussion

Although STS instruction selects merely a few key concepts for deep exploration, students, as result of the instruction, could construct more fully developed and highly integrated cognitive structures than did students receiving traditional instruction. Especially, after a long-term STS treatment (i.e., eight months in this study), the STS group students exhibited a richer texture of knowledge frameworks and their cognitive structure outcomes were enhanced in various dimensions. Educators have proposed that knowledge acquired in well-connected ideational networks is more meaningful and more useful for further applications (Ausubel *et al.* 1978, West and Pines 1985). Many earlier STS-related studies showed that STS students' science achievement did not outperform that produced by conventional teaching strategies when measured by standard achievement test (see a review by Aikenhead 1994). Educators and researchers have suspected that traditional ways of testing or evaluation can not discriminate the meaningfulness or real understanding of students' science learning (Novak 1985). This study may provide another way of proving the effectiveness of STS instruction on students' conceptual learning. The results of this study also somewhat resolve the fear of missing essential science content as a result of using STS instruction. Moreover, this study was conducted in an eastern country where educational practice is usually more traditional-oriented; however, the findings of this research, consistent with numerous studies completed in western countries (for example, Yager and Tamir 1993), support the implementation of STS instruction.

Research literature has documented the gender difference of achievement, attitude and learning strategies in science, often favouring male students over female ones (Kenway and Gough 1998). Although this study did not provide comparative data for males, this study revealed some evidence that, as a result of STS instruction, female students displayed statistically better cognitive structure outcomes than would have been expected based on traditional approaches to science education. This suggests that these female students employed more meaningful learning modes and deeper information processing strategies in organizing scientific information when learning by the STS approach. This further implies that STS-oriented instruction may be a potential way to narrow the gap between male and female students' performance in learning science. Moreover, it is generally recognized that female students prefer to discuss social-related issues during learning or to participate in learning activities leading to a social-oriented career. Hence, when compared to traditional teaching methodology, which emphasizes the presentation of fact-based scientific knowledge, STS instruction may be a closer fit to female students' learning preferences and also foster greater learning motivation. The studies completed by Pell (1985) and Solomon (1994) could also support such an expectation. They found that female students viewed 'considering social implications' and 'thinking deeply about personal views' as important variables contributing to their enjoyment and achievement of learning science, and female students also more likely (than male students) had opinions that had been socially constructed by collaborating with peers. The lesson content and teaching methods of STS instruction, clearly, fulfill their learning styles and preferences.

The findings of this research also support the practice of constructivism in science education, because the features of STS instruction are congruent with those of so-called ‘constructivist teaching’, emphasizing an open-ended approach to instruction and highlighting students’ autonomy, learning through social negotiation and building on prior knowledge (Yager 1995). For example, the STS group students in this study were often asked to work together to start with on-their-own problems, to explore other students’ points of views, to collect some relevant information for themselves and then to make a decision or reach a consensus or a shared understanding within their group. Although constructivism is still a controversial topic in science education (Matthews 1994, Phillips 1995, Osborne 1996, Nola 1997), the position of this paper, as that suggested by Tobin and Tippins (1993), Staver (1998) and Tsai (1998c), asserts that constructivism is a sound theory to help science educators interpret how students learn science as well as to explicate the practice of science and science teaching. The results of this study also support a theoretical principle of cognitive science that an open-ended approach of instruction (for example, STS instruction) will promote the development of students’ ideational networks (Anderson *et al*. 1998).

This study also provided some evidence that learners’ scientific epistemological beliefs interacted with the instructional condition (traditional versus STS) in determining students’ cognitive structure outcomes. The interaction suggested that constructivist views of science may facilitate students’ learning through STS instruction, especially in the beginning stage of implementing STS instruction. It is plausible to expect that students with the beliefs that science knowledge is an invented reality, which is constructed through social negotiations and contextual impacts (i.e., constructivist-oriented SEBs), could well perceive the usefulness of STS instruction, because it addresses more of their own epistemological orientations towards science. On the other hand, students with the views that science is a collection of objective and accurate facts (i.e., empiricist-aligned SEBs) could perform better on fact-based traditional instruction. Windschitl and Andre’s (1998) study shows a somewhat similar finding that students with more advanced epistemological beliefs learned more with a constructivist-based instructional treatment, while students with less developmentally advanced beliefs achieved better in traditional instruction. A proper understanding of constructivist views about the epistemology of science could be a prerequisite of implementing STS-oriented instruction. Traditional science education, however, is usually conducted in the paradigm of the empiricist epistemology (Duschl, 1988). Consequently, science students as well as teachers may not properly perceive the usefulness of STS instruction. Science educators, then, need to explore students’ scientific epistemological beliefs prior to conducting STS-based instructional activities. Further exploration about how to help students (or even science teachers) acquire a proper understanding about the constructivist epistemology of science could be another important research question for investigation.

Acknowledgement

Funding for this research work was provided by National Science Council, Taiwan, ROC under grant NSC 87-2511-S-009-011. The opinions expressed in this article do not necessarily reflect the position of National Science Council, Taiwan, ROC.

An early version of this paper was presented at the annual meeting of National Association for Research in Science Teaching, Boston, MA, 1999.

Notes

1. Although some researchers recommend avoidance of using the term 'constructivist' to describe one's philosophical position of science (for example, Loving 1997: 448), this paper still uses the term because science educators in general may be more familiar with it. The constructivist philosophy of science is oriented to instrumentalism, contextualism, relativism and anti-realism.
2. A prior study (Tsai 1996) revealed that one item in the Chinese version of Pomeroy's (1993) questionnaire did not show adequate consistency in assessing students' SEBs. The item is 'the best way to prepare to become a scientist is to master the scientific body available in the finest texts'. This study excluded the item when surveying students' SEBs.
3. As described previously, students' possible SEB change resulting from STS instruction was reported in another paper (Tsai 1999b). It seems that, in the final stage of research treatment, STS group students' SEBs were likely more oriented to constructivist views of science.
4. As mentioned earlier, this study administered three corresponding SEB surveys for the cognitive structure assessments. In this case, the study used student SEB results gathered from the first SEB survey. A similar rule (using corresponding SEB and cognitive structure data for regression analyses) was applied to all regression models.

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