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ABSTRACT

This proceedings covers the domain and content areas of learning and learners; curriculum and materials; instruction (including computer-assisted instruction); assessment and evaluation; history and philosophy of science; teacher preparation and professional development; and related areas of interest including environmental, special, health, medical, and information education. Papers in this volume include: (1) "A Comparison of 3-D Mental Models in Solving Visuospatial Problems between Gifted and Nongifted High School Students" (Shih-Tseng Huang and Chon-Wen Shyi); (2) "Interaction between Different Gender Students and Their Teacher in Junior High School Biology Classes" (Hsiao-Ching She); (3) "Biology Teachers' Knowledge Base of Instructional Representations" (Sheau-Wen Lin and Jong-Hsiang Yang); (4) "Understanding of the Nature of Science of Senior High School Students" (Chen-Yung Lin); (5) "Cultivating Capabilities of Teachers in Promoting Student Creativity: Designing STS Exploratory Environment" (Cheng-Hsia Wang); (6) "Aboriginal Children's Alternative Conceptions of Animals and Animal Classification" (Shih-Huei Chen and Chig-Hsiung Ku); (7) "A Study on the Technological Literacy of Elementary and Junior High School Students in Taiwan" (Ta-Wei Lee, Wei Lin, Kuo-Hung Tseng, and Kuang-Chao Yu); (8) "Science Teachers' Intentions To Teach about HIV/AIDS" (Weir-Sen Lin and John T. Wilson); (9) "Enhancing College Students' Attitudes toward Science through the History of Science" (Huann-Shyang Lin); (10) "Impacts of an Inquiry Teaching Method on Earth Science Students' Learning Outcomes and Attitudes at the Secondary School Level" (Song-Ling Mao and Chun-Yen Chang); (11) "Teaching Competencies Assessment Approaches for Mathematics Teachers" (Shian Leou); (12) "Software Based on S-P Chart Analysis and Its

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CONTENTS

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A Comparison of 3-D Mental Models in Solving Visuospatial Problems between Gifted and Nongifted High School Students†

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Abstract

Construction of three-dimensional mental models is often required for solving many spatially related problems. In three experiments, we examined whether differences existed in the 3-D mental models constructed by gifted and nongifted high-schoolers. In Experiment 1, subjects were presented with 2-D orthographic projections of a 3-D object and were asked to judge whether or not the projected views were compatible with one another. The results indicated that the subjects experience more difficulty in construction when dealing with objects of higher complexity. However, without explicit instructions, neither gifted nor nongifted high school students seemed to engage in constructing 3-D mental models while solving the compatibility task. In Experiment 2, subjects were explicitly told to construct 3-D mental models while viewing 2-D orthographic projections. The results showed that gifted students spent less time on construction than the nongifted students did, and that male students spent less time than their females counterparts. Experiment 3 examined the possibility to mentally rotate a 3-D model during construction. Gifted students performed more accurately than nongifted students in identifying 3-D objects. Similar differences were also found between male and female students. These results suggest that gifted students are more efficient at constructing 3-D mental models than nongifted students, when they are asked to do so. The relationship between gender difference and giftedness is also discussed.

Key Words: giftedness, 3-D mental models, gender difference

I. Introduction

Given that one of the major goals of the natural and biological sciences is to understand the structure of the physical world, macro as well as micro in scale, it is not unreasonable to assume that spatial abilities may play an important role in an individual's scientific and mathematical aptitudes (Benbow, 1988, 1992; Geary, 1996). During the past two decades, many studies have attempted to understand the relationship between spatial abilities or mathematical abilities and sex differences; the relationship between spatial abilities and scientific aptitude per se, however, has not been adequately addressed (Geary, 1996; Horowitz & O'Brien, 1985; Sternberg & Davidson, 1986; Voyer, Voyer, & Bryden, 1995). The general assumption appears to be that since there are many more men than women going into fields such as the sciences and engineering, and that there are also demonstrable differences in spatial and mathematical abilities

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between males and females (Geary, 1996; Voyer, Voyer, & Bryden, 1995), therefore, the relationship between scientific and mathematical aptitudes and spatial abilities must exist and be self-evident. However, more direct evidence is needed to prove these assumptions. Evidence is particularly needed when we consider spatial abilities that are used for constructing a three-dimensional (3-D) mental model from two-dimensional (2-D) displays, a task frequently encountered in spatial ability tests measuring spatial visualization, such as paper folding, cube counting, and spatial views (Levy & Levy, 1992). The main goal of our study was to reduce the gap in our knowledge in this regard.

The process of constructing 3-D mental structures is essential in everyday life. We usually make inferences to figure out the mapping relation between external information and its internal representations. This mapping can be very selective if some of the external features are more salient than others in that the corresponding internal representations are primarily representations of those salient features. There are also cases, however, in which mental representations of structure in the world may correspond well to those of external ones in a depictive or analog sense (Kosslyn, 1994; Shepard, 1994). As demonstrated by Cooper and her colleagues, people may use different strategies to solve spatially related problems in that they may or may not mentally construct the corresponding 3-D structures (Cooper, 1988, 1989).

In order to understand the process and the nature of constructing 3-D mental models, we recently conducted a series of experiments in which subjects were given problems that required constructing a 3-D mental model of an object while viewing its 2-D orthographic projections. We then presented isometric drawings of 3-D objects to probe the internal representations that were created in the course of problem solving (Huang & Shyi, 1994, 1995, 1997; Shyi & Huang, 1995). This procedure was adopted from that used in a number of studies reported by Cooper and her colleagues (Cooper, 1988,1989, 1990, 1991; Cooper & Mumaw, 1985). In Cooper's (1988, 1989) studies, subjects were first asked to perform a compatibility task, in which they were shown a set of orthographic projections of the top, front, and right views of a 3-D target object. The three orthographic projections were presented in two consecutive slides; the first slide contained the top and front sides and a blank placeholder for the right side, and the second slide contained only the projection of the right side. Subjects were asked to judge whether or not the orthographic projections presented in the two slides were compatible with one another in the sense that the same object was portrayed by the projected views.

Subjects may be able to solve compatibility problems via at least two different strategies. First, they may merely examine the local features contained in each of the three projected views and try to determine if matches exist among those local features. Or, they may opt to construct a 3-D mental model of the likely object from the first two projected views and then verify the compatibility of the third projected view against the constructed 3-D model. In order to gain insight into the strategies that subjects actually used, Cooper asked them to perform an unexpected recognition task, following the compatibility task. In a forced-choice format, two isometric drawings of 3-D objects were shown side by side in each trial, and subjects had to decide which object was the one whose orthographic projections presented in the compatibility task. Evidence suggesting that the subjects indeed were constructing 3-D models when solving the compatibility problems was indicated by the fact that the contingent probability of correctly choosing an isometric view of an object in the recognition task, given that the object's corresponding compatibility problem was solved correctly (PCC), was greater than the contingent probability when the compatibility problem was not solved correctly (PCI) (Cooper, 1990).

Following Cooper's (1988, 1989, 1990) paradigm, Huang and Shyi (1994, 1995; Shyi & Huang, 1995) used a $3 \times 3 \times 3$ based cube, consisting of 27 small blocks, and removed 2, 5, or 8 blocks from the base cube to construct stimulus objects varying in complexity. They showed that the possibility of constructing a 3-D mental model was closely related to a 3-D object's rated complexity (and the rated complexity of its corresponding 2-D orthographic projections). For example, subjects were more likely to use a constructive strategy for solving compatibility problems with orthographic projections of less complex objects than they were to do so when more complex objects were used. They also found that the constructed 3-D models were incomplete in that more structural details were preserved at the focal attentional region during problem solving than in the unfocused area (Huang & Shyi, 1997). Furthermore, 3-D models for an object with low complexity appeared to be more complete than those for an object with high complexity. In the present study, we aimed to extend Cooper's and Huang & Shyi's studies to compare the abilities in constructing 3-D mental models between scientifically gifted high school students and their nongifted counterparts. To that end, three experiments were performed. In Experiment 1, we examined whether gifted and nongifted students differed in their overall performance in solving compatibility problems. In Experiment 2, we explicitly asked subjects to construct 3-D models of an object while viewing its 2-D orthographic projections. In particular, we wanted to know whether or not gifted and nongifted high school students would differ in how complete their constructed 3-D models were. Finally, in Experiment 3, we examined whether or not mental rotation was required for constructing 3-D models and if so, whether or not gifted and nongifted students would also differ in that regard.

II. Experiment 1

The purpose of Experiment 1 was twofold: First, we attempted to see whether or not our findings with college students (Huang & Shyi, 1994, 1995; Shyi & Huang, 1995) could be generalized to high school students. Our studies have shown that as the complexity of an object increases, the likelihood of solving compatibility by constructing 3-D mental models decreases. Likewise we expected to find, among high-schoolers, stronger evidence for 3-D models for objects with low and perhaps medium complexity rather than for those with high complexity. Second, we wanted to see whether differences in strategy existed between gifted and nongifted high school students in solving spatial problems involving 3-D model construction.

1. Method

A. Subjects

Thirty-four high school students from Chia-Yi Provincial High School and Chia-Yi Girls High School, all in the second year of high school, served as subjects in this experiment; each subject was rewarded with a gift of NT$100 at the conclusion of their participation. Sixteen of them were scientifically gifted students, nine males and seven females. The students were identified as scientifically gifted because of their outstanding academic performance in courses covering natural sciences (physics and chemistry), biology, and mathematics. These students were selected and placed together to form a unique class in each school as a result of their academic performance. Eighteen were nongifted students, half males and half females. The nongifted students were randomly selected from the classes that were not identified by the respective schools as gifted. All the subjects had vision that was normal or corrected to normal.

B. Stimulus Materials and Apparatus

The stimulus objects used in Experiment 1 were those constructed and used in our previous study (Huang & Shyi, 1994, 1995; Shyi & Huang, 1995), consisting of a set of 30 objects representing three levels of complexity. There were 10 objects for each level of complexity, and the mean rated complexity was 28.19 (*SD*=8.16) for the low group, 44.12 (*SD*=10.82) for the medium group and 70.05 (*SD*=10.49) for the high group. (See Shyi & Huang, 1995, for a complete exposition of the rating and selection procedure.) The least and most complex objects of each complexity group, 6 objects in total, were used for practice. As a result, eight objects in each group, totaling 24 objects, served as the target stimuli (*M*'s=28.62 for the low group, 44.00 for the medium group, and 69.44 for the high group, respectively). For each target object, we also constructed and selected a corresponding distractor to be used in the isometric recognition test because the test took the form of two-alternatives-forced-choice (2AFC).

For each target object, we first constructed 6 possible distractors, each sharing an orthographic view (top, front, or right) with the target. Similarity and complexity ratings were taken, and the distractor with medium similarity and complexity comparable to its corresponding target was selected. The mean complexity rating for the distractors was 22.98 (*SD*=4.41) for the low group, 35.25 (*SD*=5.05) for the medium group, and 57.24 (*SD*=5.91) for the high group, which did not reliably differ from the mean complexity of their corresponding targets (Huang & Shyi,1994; Shyi & Huang, 1995). Isometric drawings of distractors and their right orthographic view were used in the present experiment. An example of the isometric (3-D) drawing and orthographic projections of a target object along with the isometric drawing of its distractor and the right orthographic view of the distractor is shown in Figure 1.

C. Procedure

Subjects participated in the experiment individually in a group test session that took place in the computer room of the respective school. Each subject had access to his or her own computer as the apparatus--an Acer 80486 PC, equipped with a color monitor--for stimulus presentation and response recording. Typically, the testing session consisted of a group of 14 to 16 students in which half were from the gifted class and the other half were from the nongifted class. Subjects were asked to perform two tasks, an orthographic compatibility task and an in-

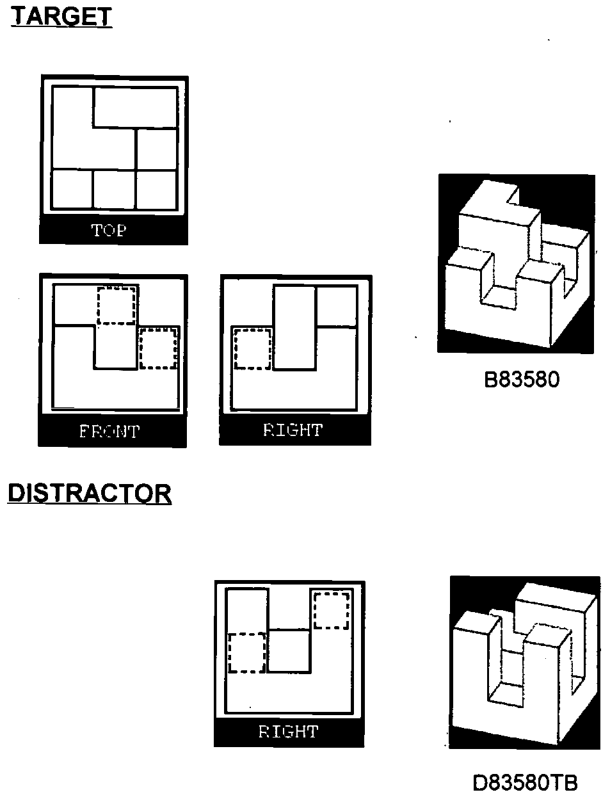

Fig. 1. An example showing the isometric (3-D) drawing of a target object and its orthographic projections (top panel) along with the isometric drawing of its distractor and the right orthographic view of the distractor (bottom panel) used in Experiment 1.

cidental recognition task. In each trial in the orthographic compatibility task, they were shown in the first frame the top and front view of a target object and an empty placeholder representing the right view, and in the second frame they were shown only the projection representing the right view. The subjects were asked to judge whether or not those three orthographic views could have arisen from the same object. They were allowed to inspect each of the two frames ad lib until they could reach an answer. At this point, they pressed designated response keys on the computer keyboard to indicate their judgments. Response latencies were recorded from the onset of the first frame to the depression of a response key; the proportion of time spent on each frame was also computed. Half of the trials entailed "yes" responses in that the third view was compatible with the previous two views; the other half entailed "no" responses because the third view was incompatible with the first two.

Immediately following the compatibility task, the subjects were given a previously unmentioned recognition task. In each trial of the recognition test, a pair of isometric drawings of 3-D objects were presented, and the subjects judged for which object orthographic projections had been presented earlier in the compatibility task. Both the compatibility and recognition tasks contained a total of 24 trials.

Table 1. The Mean Proportion of Correctly Solving Compatibility Problems as a Function of Gender, Giftedness, and Object Complexity in Experiment 1 (N=34)

	Gifted		Nongifted	
Complexity	M	F	M	F
Low	.87 (.24)	.79 (.26)	.85 (.18)	.76 (.14)
Medium	.89 (.10)	.77 (.18)	.83 (.14)	.74 (.18)
High	.79 (.09)	.64 (.24)	.74 (.22)	.61 (.10)

Note: The numbers in parentheses are standard deviations; M=males, F=Females.

2. Results and Discussion

A. Orthographic Compatibility Task

The overall accuracy in the compatibility task was 77.5%, which was almost was identical to the results obtained by Cooper (1990) (76.5%) and by Huang & Shyi (1994) (77%). The means and standard deviations for each condition are listed in Table 1. Subjects' accuracy in solving compatibility problems was submitted to a 2 (sex)×2 (class: gifted or nongifted) x 3 (complexity) mixed analysis of variance (ANOVA). The main effect of sex approached significance, $F(1,30)=5.17$, $MSe=.06$, $p<.05$, indicating that male subjects (M=83%) outperformed their female counterparts (M=71%); the main effect of class failed to reach significance, $F<1$. As in the study by Huang & Shyi (1994; Shyi & Huang, 1995), the main effect of complexity was highly significant, $F(2, 60)=8.42$, $MSe=.02$, $p<.001$. Further analyses indicated that the subjects did equally well with objects of low and medium complexity (M's=82% and 81%, respectively), and did significantly worse with those of high complexity (M=69%). The difference between the gifted and nongifted students was not significant, however, $F<1$. No other main effects or interaction were significant, F's<1 or p's>.35.

The subjects on average took about one minute (60.51 s) to correctly solve a problem, which was about the same amount of time found by Huang and Shyi (1994) (62.10 s), where college students were used. The mean solution times and their standard deviations for each condition are listed in Table 2. The same ANOVA reveals only one reliable main effect: complexity, $F(2,60)=21.08$, $MSe=231.04$, $p<.001$. The subjects spent more time solving problems of high complexity (M=74.46 s) than solving problems of low and medium complexity (M's=52.22 s and 54.85 s, respectively); the latter two did not differ from each other, $F<1$. No other main effects nor any of the interactions were found to be significant, F's<2.45 or p's>.13.

B. Incidental Recognition Test

The average accuracy of recognition was 64%, replicating that obtained by Huang and Shyi (1994) (.63), but lower than that obtained by Cooper (1990) (.85). Recognition accuracies were submitted to the same mixed ANOVA as before. Again, only the main effect of complexity was reliable, $F(2,60)=7.58$, MSe =.03, p=.0012, reflecting the fact that the subjects recognized more objects of low and medium complexity (M's=.69 and .68) than of high complexity (M=.54).

C. Contingency Probability

The critical evidence for claiming that subjects solved the compatibility problems by constructing a 3-D mental model from 2-D displays was that the probability of correctly recognizing a target object when its corresponding compatibility problem was correctly solved (PCC) was greater than the probability of correctly recognizing a target object when its compatibility problem was not correctly solved (PCI) (Cooper, 1990; Huang & Shyi,1994; Shyi & Huang, 1995). The average PCC was .65 and average PCI was .59. Although the average PCC was reliably greater than chance, $t(32)=7.36$, $p<.001$ and average PCI was not, $t(32)=1.85$, $p>.08$), their difference failed to reach significance, $t(32)=1.15$, $p>.20$. Furthermore, when the overall PCC and PCI data were submitted to a 2 (sex) × 2 (class) × 2 (type: PCC or PCI) mixed ANOVA, none of the main effects nor any interactions were found to be reliable (F's<1). These results do not allow us to conclude with confidence that high-schoolers were actually engaged, at least for some trials, in constructing 3-D models when they were solving the compatibility problems. Moreover, there is no indication that gifted students were more inclined to adopt a constructive strategy than their nongifted counterparts in solving those problems.

Table 2. The Mean Time (in sec) Spent on Solving Compatibility Problems as a Function of Gender, Giftedness, and Object Complexity in Experiment 1 (N=34)

	Gifted		Nongifted	
Complexity	M	F	M	F
Low	45.33	52.22	49.32	61.99
	(27.11)	(14.28)	(15.66)	(24.01)
Medium	46.91	62.19	50.54	61.41
	(13.95)	(16.48)	(22.65)	(18.26)
High	77.61	73.84	67.00	79.24
	(20.18)	(17.96)	(25.83)	(24.98)

Note: The numbers in parentheses are standard deviations; M = males, F=Females.

It is worth noting, nonetheless, that nearly half of high-school students who participated in Experiment 1, like the college subjects we tested before, exhibited missing data on PCIs across three levels of complexity (N=16) (Huang & Shyi, 1994, 1995; Shyi & Huang, 1995). (Note that PCIs would be incomputable if subjects failed to give any incorrect answers for the compatibility problems; see Shyi & Huang, 1995, for further discussion.) As in our previous studies, we instead analyzed subjects' PCC data via a 2 (sex) × 2 (class) × 3 (complexity) mixed ANOVA. The main effect of complexity was found to be significant, $F(2, 60)=6.98$, $MSe=.05$, p<.01. Objects of low (.70) and medium (.70) complexity had higher PCCs than did those of high complexity (.52), $F(1,30)=11.06$, $MSe=.04$, $p<.01$ for low versus high, and $F(1,30)=9.35$, $MSe=.05$, $p<.01$ for medium versus high, respectively. No other effects were reliable, F's<1.3, p's>.28. Previously, we have taken such a finding to suggest that subjects were more inclined to use a constructive strategy in solving compatibility problems with low and medium complexity than in solving problems with high complexity. In the present study, however, this conclusion must be drawn with caution because the overall PCC did not differ reliably from the overall PCI, which gave no clear clues that compatibility problems were solved by constructing 3-D mental models.

In summary, the results of Experiment 1 to a large extent replicated our previous findings obtained with college students, and this was particularly the case insofar as the effect of object complexity is concerned. We found reliable effects of object complexity on a number of measures such as accuracy of compatibility task, time spent on solving problems, accuracy of recognition rate, and contingency probability of PCC. These findings suggest that the high school students, like their college counterparts, had a more difficult time solving compatibility problems with high complexity. Unlike the college subjects, however, the high-school subjects exhibited no clear indication that they would voluntarily engage in constructing 3-D models in solving those problems; as a consequence,

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no reliable difference in problem solving strategy could be expected between gifted and nongifted students.

The fact that the high-school subjects did not voluntarily adopt constructive strategies to cope with the compatibility task may not be too surprising given that, in the instructions provided for the task, there was no mention of and no clues were given that a constructive strategy would be useful for solving compatibility problems. In fact, Cooper reported in her initial studies that she was surprised by the fact that her (college) subjects voluntarily engaged in constructing 3-D mental models despite that all problems could have been solved using local features matching strategies (Cooper, 1988, 1989). Therefore, what we demonstrated in Experiment 1 was that the high-school students, unlike college students, faithfully followed the instructions they received for solving the compatibility task and were not motivated to use any alternative strategies that were not mentioned or implied in the instructions. We, therefore, decided for the following experiments to change the compatibility task to a *construction* task, where subjects were explicitly asked to construct 3-D mental models while viewing 2-D orthographic displays (Huang & Shyi, 1995, 1997).

III. Experiment 2

In Experiment 1, we failed to find a difference in performance between gifted and nongifted high school students. Moreover, there was no evidence suggesting that students engaged in 3-D model construction to solve problems when they were not explicitly instructed to do so. In Experiment 2, we therefore explicitly instructed our subjects to engage in constructing 3-D mental models while viewing the corresponding 2-D displays, with the hope that the construction task would allow us to answer the questions we raised with regard to Experiment 1. Another goal in Experiment 2 was to examine the characteristics of the 3-D models constructed by the high-school students. In particular, we wanted to know whether or not the 3-D models constructed by high-schoolers would exhibited the same properties as did those constructed by the college students. As mentioned earlier, we have found in previous studies that object complexity affected the completeness of the constructed 3-D models in that more structural details were preserved for models of objects with low complexity than those of objects with high complexity. Furthermore, more structural details were preserved in the focal-attention region than in the peripheral region (Huang & Shyi, 1995, 1997). Here, we hoped to see whether the same conclusions could be drawn for high-school subjects and whether or not the 3-D models constructed by gifted students would differ from those constructed by their nongifted counterparts.

1. Method

A. Subjects

Thirty-five high-school students, 19 males (9 gifted and 10 nongifted) and 16 females (8 gifted and 8 nongifted) from the same classes and schools as in Experiment 1, participated in Experiment 2. As in Experiment 1, each subject was rewarded with a NT$100 gift for their participation. All the subjects had vision that was normal or corrected to normal.

B. Stimuli Materials and Apparatus

In order to test our predictions regarding the nature of the mental models constructed, we created a new set of stimulus objects. To ensure that the subjects could perform 3-D construction, we used stimulus objects that were of moderate level of complexity so as not to defeat a constructive strategy. Twenty-six stimulus objects were chosen from the original set of 135 objects; all were of the kind in which 5 blocks were removed from the base cube. Half of them had relatively low complexity ratings (*M*=29.61), and 13 had medium to high complexity ratings (*M*=50.82) (Huang & Shyi, 1995, 1997). For each target object, two distractors were then created. The *c-distractors* were generated by adding or removing one or two blocks from the target object in the intersecting area specified by the top and front view, and the *p-distractors* were created by adding or removing one or two blocks in a region outside the intersecting area (see Huang & Shyi, 1995, for a detailed description of stimuli construction and selection). These distractors were created to test the prediction that when subjects make an error in misidentifying the target object, they are more likely to pick the p-distractor than the c-distractor because the constructed mental model is more clearly specified in the focal region than in a peripheral region. Examples of a target object and its matching c- and p-distractors are illustrated in Figure 2.

For a given target, its c- and p-distractors were altered by the same amount as much as possible to the same degree. The target objects and their distractors were rated by another group of 10 subjects to ensure that, overall, the two sets of stimuli had comparable complexity (*M*'s 38.58 for targets and 39.20 for

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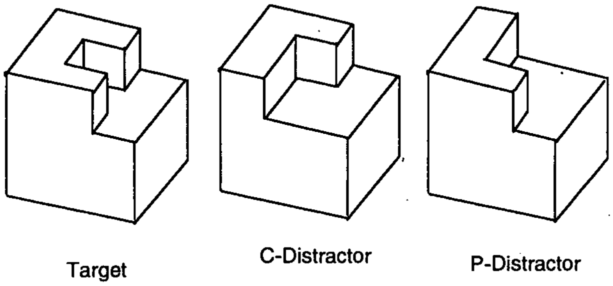

Fig. 2. Examples illustrating a target object and its respective c-distractor and p-distractor, and their orthographic projections in Experiment 2. Note how the two distractors differed from the target either centrally or peripherally.

distractors). Finally, we drew a set of two orthographic projections (top and front views) for each target object and their distractors. The same apparatus used in Experiment 1 was used here for stimulus presentation and response recording.

C. Procedure

As before, subjects were tested individually in group sessions as in Experiment 1. They were asked to perform two tasks. In the first task, the subjects were shown, in each trial, a pair of orthographic projections (top and front view) and were explicitly told to form or construct a mental image of a 3-D object that would correspond to the presented 2-D views. As Cooper's (1990) and Huang & Shyi's (1994, 1995) studies have demonstrated, only two orthographic views were needed to uniquely determine the corresponding 3-D object, and the third orthographic view was primarily for the purpose of verification once the 3-D model was constructed. Upon completing the construction of a mental model, the subjects pressed the spacebar on the keyboard, and an array of three isometric drawings of 3-D objects appeared on the screen. One was the target, corresponding to the orthographic views shown earlier, and the other two were c- and p-distractors, respectively. The positions of the three testing objects were randomly assigned. The subjects were asked to indicate which 3-D object resembled most to the one they had imagined. After they responded, the subjects were asked to rate how confident they were in their judgments. There were a total of 26 trials.

Immediately following the construction task, the subjects were given an unexpected recognition test. Each trial in this test consisted of two pairs of orthographic projections representing the top and front views. One pair corresponded to those shown at the beginning of each trial in the construction task; the other pair, not shown at all in the construction task, corresponded either to the matching c-distractor or the matching *p*-distractor. The reason for including an orthographic recognition test was that we wanted to evaluate the possibility that subjects might have solved the construction task not by mentally imagining 3-D objects, but by memorizing the 2-D target projections and then unpacking or decomposing the 3-D objects into sets of 2-D projections and locating the match.

Table 3. The Mean Accuracy of Construction Task as a Function of Gender, Giftedness, and Object Complexity in Experiment 2 (N=35)

	Gifted		Nongifted	
Complexity	M	F	M	F
Low	.91 (.17)	.82 (.13)	.92 (.09)	.90 (.09)
Medium	.79 (.19)	.75 (.17)	.76 (.19)	.78 (.18)

Note:The numbers in parentheses are standard deviations; M=males, F=Females.

2. Results and Discussion

A. Construction Task

The average accuracy in selecting the 3-D object that corresponded to the 2-D orthographic projections was quite high (83.40%). As can be seen in Table 3, the results of ANOVA indicate that only the main effect of complexity was reliable, $F(1, 31)=28.41$, $MSe=.01$, $p<.0001$. The subjects performed better on problems with lower complexity (M=.90) than on those with higher complexity (M .77). This result is quite consistent with that found in the Experiment 1 and with those of previous studies (Huang & Shyi, 1994, 1995; Shyi & Huang, 1995). No difference was found between gifted and nongifted students, however, nor between students of opposite sex. Furthermore, none of the interactions was significant, F's<1 or p's>.50.

The mean time spent on constructing a 3-D mental model was 27.13 s, which was longer than that spent on selecting a 3-D isometric drawing, 12.78 s, leading to a total solution time of 39.91 s for each problem. The results of ANOVA for total solution time indicate that the main effects of class, sex, and complexity were all significant. As shown in Table 4, gifted students (M=34.85 s) needed less time than nongifted students did (M=44.70 s), $F(1,31)=5.41$, $MSe=348.80$, $p<.05$; females needed more time (M=49.98 s) for solution than males did (M=31.44 s), $F(1,31)=17.56$, $MSe=348.80$, $p<.001$; finally, problems with higher complexity (M=47.53 s) required more time to solve than did those with lower complexity (M=32.30 s),

Table 4. The Mean Time (in sec) Spent on Construction Task as a Function of Gender, Giftedness, and Object Complexity in Experiment 2 (N=35)

	Gifted		Nongifted	
Complexity	M	F	M	F
Low	20.54	36.63	28.84	45.54
	(8.03)	(12.78)	(11.82)	(11.84)
Medium	32.42	51.90	42.98	65.87
	(11.60)	(15.25)	(21.44)	(14.34)

Note: The numbers in parentheses are standard deviations; M=males, F=Females.

Table 5. The Mean Number of Errors in the Construction Task of a Function of Gender, Giftedness, and Error Type in Experiment 2 (N=35)

		Gifted		Nongifted	
Complexity	Error type	M	F	M	F
Low	P	0.44	1.38	0.60	0.62
		(0.73)	(1.19)	(0.84)	(1.06)
	C	0.78	0.50	0.40	0.50
		(1.64)	(0.76)	(0.52)	(0.53)
Medium	P	1.89	1.88	2.10	2.00
		(2.09)	(1.55)	(1.60)	(1.60)
	C	0.89	1.38	1.00	1.00
		(0.78)	(1.19)	(1.15)	(1.07)

Note: The numbers in parentheses are standard deviations; M=males, F=Females.

$F(1,31)=93.40$, $MSe=44.08$, $p<.0001$.

After the subjects made their choices of 3-D objects, they were asked to rate how confident they were in their judgments. The gender difference was found to be reliable, $F(1, 31)=11.85$, $MSe=.36$, $p<.01$, in that males (M=4.36) appeared to be more confident in their judgments than females (M=3.66). A significant class by gender interaction indicates that, while no difference existed between gifted and nongifted male subjects (M's=4.28 and 4.44 respectively), the gender difference arose mainly from the fact that gifted females (M=4.03) in general had higher confidence than nongifted female subjects (M=3.29).

Most importantly, subjects misidentified *p*-distractors (M=2.71) as targets more frequently than they misidentified *c*-distractors as targets (M=1.60), $F(1,31)=15.81$, $MSe=.68$, $p<.001$. The main effect of complexity also reached significance in that more errors were made for the objects with higher complexity (M=1.52) than for those with lower complexity (M=.64), $F(1,31)=30.28$, $MSe=.85$, $p<.0001$. The interaction between the type of error and complexity was marginally significant, $F(1,31)=3.70$, $MSe=1.09$, $p=.06$. As can be seen in Table 5, while subjects made about an equal number of c- and p-type errors with objects of low complexity (M's=.74 and .54, respectively), $F(1,31)=1.51$, $MSe=.54$, $p=.23$, they made more *p*-type errors (M=1.97) than *c*-type errors (M=1.06) with more complex objects, $F(1,31)=11.33$, $MSe=1.24$, $p<.01$. Gifted and nongifted students had a similar tendency to make more errors on *p*-distractors than on *c*-distractors, however, $F<1$.

These findings again replicate those that were obtained with college subjects (Huang & Shyi, 1995, 1997), and they suggest that the likelihood of constructing a 3-D mental model decreased as the complexity increased, and that the extent to which structural details were preserved in the model decreased as object complexity increased. Furthermore, these results provide evidence to support the claim that the 3-D mental models contained more details in the region of focus of attention, in this case the area of the intersection of the top and front orthographic views, and that details outside the focal region were not as clear or as accessible as those located in the focal region.

B. Recognition Test

An incidental recognition test of 2-D orthographic projections was conducted at the end of the experiment. In each trial, subjects had to identify which of the two pairs of orthographic projections were presented earlier in the construction task. The overall average accuracy of the recognition test was 70%. This recognition accuracy was submitted to a 2 (sex) × 2 (class) × 2 (complexity) mixed ANOVA. The main effect of complexity was marginally reliable, $F(1,31)=3.46$, $MSe=.01$, $p<.07$. The subjects tended to recognize more correctly for problems with lower complexity (M=.73) than for those with higher complexity (M=.67). The three-way interaction among sex, class, and complexity was also significant, $F(1, 31)=5.99$, $MSe=.01$, $p=.05$. Further analysis indicated that while the difference did not vary between male and female gifted subjects in solving problems with different levels of complexity (male-female were -.08 (low) and .03 (medium)), $F(1,15)=1.33$, $MSe=.02$, $p=.27$, it did vary between those of male and female nongifted subjects (male-female were .05 (low) and .11 (medium)), $F(1,16)=7.58$, $MSe=.007$, $p<.05$.

C. Contingent Probabilities

An important reason for including the *ortho-*

graphic recognition test was to examine the possibility that subjects performed the construction task not by mentally imagining 3-D models but by memorizing the target orthographic views and unpacking the isometric drawings of each 3-D object into their respective set of orthographic views, and then comparing those with the ones they had memorized. If so, we would expect a high correlation between the accuracy in the construction task and that in choosing the correct (old) set of orthographic projections. This was indeed what we found—the correlation was modest and yet reliable, $r(35)=.34$, $p<.05$. However, an unpacking or decomposing strategy would not predict that differences existed between the contingency probability of choosing the correct set of orthographic projections given that the 3-D object construction was done correctly (PCC) and the contingent probability of choosing the correct set of orthographic views given that construction was done incorrectly (PCI). (Note that the implications of the contingent probabilities computed here are quite different from those of the contingent probabilities computed in Experiment 1, which were used to index the extent to which compatibility problems were solved by constructing 3-D mental models.) If the subjects were merely unpacking the 3-D objects into a set of 2-D patterns, there seemed no reason to expect that PCC would be in any way different from PCI. However, when we submitted the overall PCC and PCI to a 2 (sex) × 2 (class) × 2 (type: PCC or PCI) ANOVA, we found that the main effect of type was to be reliable, indicating that PCC (.72) was greater than PCI (.59), $F(1, 29)=5.33$, $MSe=.04$, $p<.05$. No other main effects nor interactions were found reliable. An unpacking or decomposition strategy also would not predict a difference in the type of error subjects committed in the construction task. There seemed to be no a prior reason that, by unpacking or decomposing, subjects should err more on *p*-distractors than on *c*-distractors, which was exactly the result we obtained.

Taken together, these results for the recognition test suggest a coexistence of an accessible 3-D mental model along with its corresponding 2-D orthographic projections in the course of the experiment; the former supported subjects' performance on the construction task, and the latter supported their performance on the recognition test. Most importantly, our results indicate that the constructed 3-D mental models were partially complete in that the region falling within the focus of construction contained more structural details than did those falling outside the focal area (Hochberg, 1982; Shyi & Peterson, 1992; Peterson & Gibson, 1991).

IV. Experiment 3

In coping with the construction task, while inspecting a set of orthographic projections (e.g., top and front view) and constructing the corresponding 3-D mental model, subjects might need to rotate their viewpoint toward the third view (e.g., right view) in order to judge which isometric drawings that were shown subsequently matched the constructed model. The basic idea is that the internal mental model may be constrained by the two displayed orthographic views. In the case where top and front views are shown, subjects may choose to construct a 3-D mental model based on a top-front perspective. Since such a perspective may occlude the right view of the object, subjects would need to perform mental rotation to allow information of the third view to be available. To do so, subjects would probably mentally rotate the constructed 3-D structure to the left in their mind's eye in order to make a required judgment. In the present experiment, we examined whether there were differences between gifted and nongifted high school students in their abilities to mentally rotate constructed 3-D models.

1. Method

A. Subjects

Thirty-five subjects, 8 gifted and 9 nongifted males and 9 gifted and 9 nongifted females, recruited from the same high schools as in the previous experiments, participated in Experiment 3. As before they were rewarded with NT$100 gifts for their participation at the end of the experiment. All the subjects had normal or corrected to normal vision.

B. Stimulus Materials

Fifteen objects with low and medium complexity, selected from the stimulus objects used in Experiment 1, served as the test material. These stimulus objects were used for the same reason to encourage subjects to engage in a construction strategy. For each target object, distractors sharing top, front, or right views with the target and with similar complexity ratings were constructed and selected (see Huang & Shyi, 1994, for details). The target and its distractor were paired and tested under rotations of 15°, 45°, or 75° along the y-axis of the display screen (i.e., depth plane). An example showing the orthographic views of the target and those of the distractor, and three rotated pairs of objects used in the construction task are shown in Figure 3.

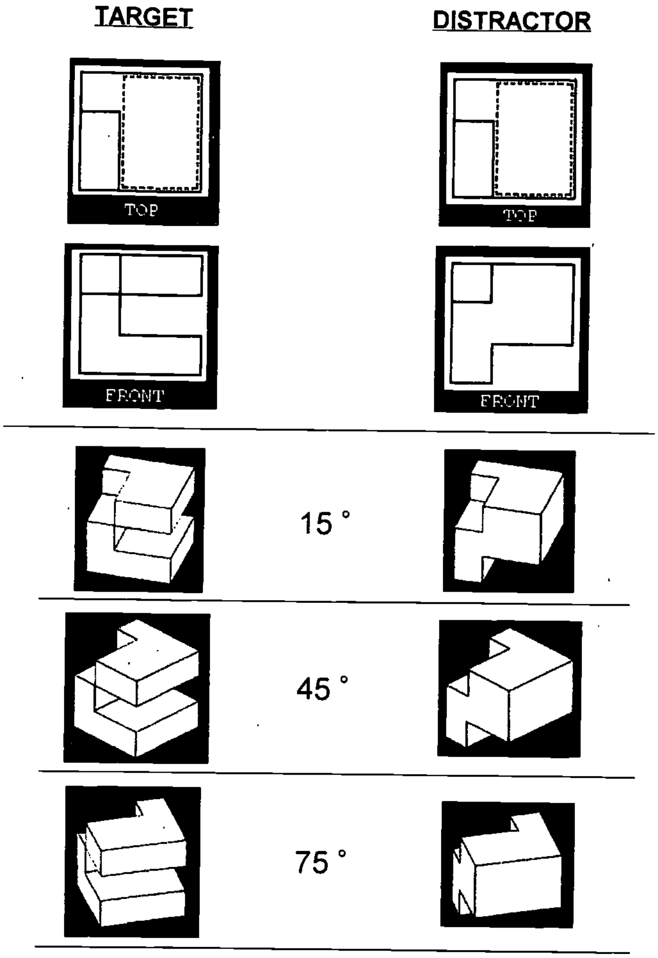

Fig. 3. An example of a target and its distractor presented at 15°, 45°, and 75° of rotation in Experiment 3.

C. Procedure

As before, each subject was tested individually in a group session. They were asked to complete two tasks: the construction task and the recognition test. In the construction task, the subjects were explicitly instructed, as in Experiment 2, to construct corresponding a 3-D mental model for each set of the orthographic projections. They were then asked to choose from a pair of objects and indicate which corresponded to the one they had imagined. The pairs of objects were rotated, with equal likelihood, 15°, 45°, or 75° along the depth plane (i.e., the *y*-axis); five trials were assigned to each rotation angle.

The second task was a recognition test, in which the subjects were shown two sets of orthographic projections and were asked to identify the set of orthographic projection presented in the construction task. One of the two sets was the target, and the other set was the orthographic projections of the paired distractor.

Table 6. The Mean Accuracy of Construction Task as a Function of Gender, Giftedness, and Rotation Angle in Experiment 3 (N=35)

	Gifted		Nongifted	
Rotation Angle	M	F	M	F
15°	.95 (.09)	.76 (.22)	.78 (.18)	.78 (.12)
45°	.97 (.07)	.73 (.28)	.89 (.14)	.64 (.28)
75°	.95 (.09)	.76 (.26)	.80 (.24)	.64 (.31)

*Note:*The numbers in parentheses are standard deviations; M=males, F=Females.

2. Results and Discussion

A. Construction Task

In general, the accuracy in the construction task (.80) was similar to that of Experiment 2 (Table 6). The accuracy data were submitted to three-way mixed ANOVA of sex, class, and angle of rotation. The main effect of gender was found to be significant in that males (.88) answered more accurately than females (.72), $F(1, 31)=11.55$, $MSe=.067$, $p<.01$,. The gifted students (.85) also appeared to perform better than the nongifted (.76) although the difference failed to reach significance, $F(1,31)=3.74$, $MSe=.067$, p=.06. No other main effects nor interactions were found to be significant, F's<1.40, p's>.25.

The mean solution time for the construction task was 24.61 s, which was slightly shorter than the mean construction time for Experiment 2. The solution times for the construction task were also submitted to a 2 (sex) × 2 (class) × 3 (rotation angle) mixed ANOVA. None of the main effects were found to be reliable, F's<1 or p's>.16. However, the interaction of rotation angle and class was reliable, $F(2, 62)=3.99$, $MSe=20.57$, p=.023. As shown in Table 7, while gifted students had a tendency of need more time to pick up the target isometric as the angle of rotation increased (25.57 s, 26.27 s, and 28.83 s for 15°, 45°, and 75° of rotation, respectively) , nongifted students exhibited an opposite trend (24.54 s, 20.68 s, and 21.81 s for 15°, 45°, or 75° of rotation, respectively).

B. Recognition Test

As in Experiment 2, an incidental recognition test of 2-D orthographic projections was conducted at the end of the overall experiment. In each trial, subjects had to identify which of the two pairs of orthographic projections were presented earlier in the construction

Table 7. The Mean Total Solution Time (in sec) Spent on the Construction Task as a Function of Gender, Giftedness, and Rotation Angle in Experiment 3 (N=35)

	Gifted		Nongifted	
Rotation Angle	M	F	M	F
15°	23.76	27.17	23.35	25.72
	(7.37)	(13.36)	(8.97)	(7.68)
45°	22.57	29.56	19.21	22.14
	(9.22)	(13.36)	(8.38)	(6.10)
75°	24.92	32.32	20.11	23.51
	(9.11)	(15.10)	(8.29)	(6.49)

Note: The numbers in parentheses are standard deviations; M=males, F=Females.

task. The overall average accuracy of the recognition test was 74%, which appeared to be slightly better than that in Experiment 2 (70%). This recognition accuracy was submitted to a 2 (sex) × 2 (class) × 3 (angle of rotation) mixed ANOVA. Only the main effect of sex was reliable, $F(1, 31)=16.22$, $MSe=.061$, $p=.0003$, indicating that males ($M=.84$) outperformed their female counterparts ($M=.64$). There was also a marginal interaction between sex and class, $F(1, 31)=3.30$, $p=.079$, reflecting the tendency that while gifted female students ($M=.72$) did much better the nongifted females ($M=.57$), gifted males ($M=.83$) performed at about the same level as did nongifted males ($M=.85$). No other main effects nor interactions were reliable, F's<1 or p's>.12.

As for Experiment 2, we included the *orthographic* recognition test to check for the possibility that the subjects performed the construction task not by using a 3-D model construction strategy, but by using a 2-D unpacking strategy. If so, we would expect a high correlation between the accuracy in the construction task and that in choosing the correct (old) set of orthographic projections. This was indeed what we found--the correlation was relatively high and reliable, $r(35)=.70$, $p<.01$. Therefore the result of the construction task could mean that the subjects in Experiment 3 used a 2-D unpacking strategy to cope with the construction task. However, we doubted that this was actually the case for the following reasons. First, recall that the subjects were asked to solve construction problems over a series of 15 trials, which was slightly more than half of what the subjects in Experiment 2 had to cope with. The smaller number of trials not only gave rise to a much lower load, thus reducing memory interference at the time of the recognition test, but also led to a much shorter retention interval between the presentation of the orthographic projections and the recognition test. Recall that it took on average 27.13 s for the subjects to solve each problem in Experiment 2, which means about 12 min had elapsed before the recognition test began, given that there were 26 problems to solve. In contrast, it took on average 24.61 s for the subjects in Experiment 3 to solve each problem, which means that only a bit more than 6 min had elapsed before the recognition test began, given there were only 15 problems to solve. Second, as we suggested for Experiments 1 and 2, the high-school students behaved very differently from the college students we tested before in that the high-schoolers appeared to be more willing to obey instructions. As a result, they were reluctant to use a strategy (e.g., 3-D model construction) for problem-solving if they were not explicitly told or encouraged to do so. We also suspected that the group testing scenario used throughout the study due to practical constraints may also have put some pressure on the high-school subjects such that they would try as much as they could to comply with instructions. Together, and including the reasons discussed in Experiment 2, we think that the high correlations between construction performance and the orthographic recognition test should be interpreted as evidence for the coexistence of accessible 3-D mental models along with their corresponding 2-D orthographic views.

In summary, the accuracy and response time of the construction task revealed that when they spent about the equal amounts of time on the construction task, gifted students solved the construction problems more accurately than did their nongifted counterparts. Similarly, male subjects performed with a higher accuracy rate than did their female counterparts when both groups spent about the same amount of time on the construction task. These results suggest that the gifted students and male subjects seemed to perform better in terms of construction accuracy.

There was no clear indication that the gifted and nongifted students differed in their abilities to rotate a 3-D model once it was constructed. Likewise, there was no evidence that males could perform better than females in that regard. In fact, the results appear to suggest that the 3-D models may have been constructed using a nonspecific perspective such that the need for mental rotation was obviated (Cooper, 1988; Marr, 1982). Of course the negative findings could also mean that we failed to use a sufficient range of rotation angle such that the specific 3-D model constructed from the top-front perspective could allow subjects to recognize isometrics rotated from 15° to 75° without invoking mental rotation. Tarr (1995; Tarr and Pinker, 1989) recently proposed a multiple-view model to account for human object recognition in which multiple representations of an object, corresponding to different viewpoints, are built during the course of familiarization. His view has received both psychophysical and neurophysiological support (Tarr, 1995; Tarr & Pinker, 1989; Logothetis & Sheinberg, 1996; Perrett, Oram, Hietanen, & Benson, 1994). In particular, Logothetis and Sheinberg, and Perrett et al. have provided estimates, based on single-cell recording from primate brains, that each representation constructed for a specific view may encompass a range of approximately 60° to 80° of viewing arc. Such findings suggest that we may need to consider a broader range of rotation angle in order to understand the operation of mental rotation.

V. General Discussion

Three experiments were conducted in the present study to examine whether scientifically gifted and nongifted students would differ in the strategy as well as product of constructing 3-D mental models from viewing 2-D orthographic projections. In Experiment 1, we replicated our previous findings of the robust effect of complexity in that subjects experienced more difficulty in construction when dealing with objects of higher complexity than with objects with lower complexity (Huang & Shyi, 1994, 1995, 1997; Shyi & Huang, 1995). Without explicit instructions, however, neither gifted nor nongifted high school students seemed to engage in constructing 3-D mental models while solving the compatibility task in Experiment 1.

In both Experiments 2 and 3, when we explicitly asked the subjects to engage in 3-D model construction while viewing 2D displays, gifted students appeared to be more efficient, in terms of both speed and accuracy, than nongifted students in problem-solving. In Experiment 2, for example, gifted students needed less time in construction to achieve the same degree of accuracy as nongifted students did. In Experiment 3, when asked to identify the corresponding 3-D structure in a recognition test in which objects were presented with different angles of rotation, the gifted high school students achieved a higher level of accuracy than did their nongifted counterparts although they spent about the same amount of time. Taken together, the results of these two experiments suggest that the gifted students had better spatial abilities and were more efficient at solving visuospatial problems.

In addition, we found that the likelihood of constructing a mental model decreased as complexity increased, and that the extent to which structural details were preserved in the constructed models decreased as object complexity increased. These results replicate Huang and Shyi's previous findings on college samples and suggest that those high school students also retained clearer 3-D mental models in regions of attentional focus. And, as a consequence that the accessibility of structures outside the focal region decreased.

To conclude, we will discuss briefly some of the implications of our results for issues related to giftedness: The first issue concerns the differential performance on the *implicit* and *explicit* tasks. It is obvious that in Experiment 1, when they were asked to perform the compatibility task which only implicitly required subjects to engage in a construction strategy, neither the gifted nor the nongifted students exhibited an inclination to construct 3-D models. Clear indication for 3-D model construction and evidence for differential abilities in 3-D construction between the gifted and nongifted studnets emerged in Experiment 2, where the subjects were explicitly instructed to engage in a construction process. It is interesting to speculate on what could have led to such differences other than the seemingly innocuous task demands, particularly in light of both Cooper's and our previous studies which consistently demonstrated that college students voluntarily adopted a constructive strategy to solve compatibility problems. We suspect that the educational practices and cultural influences prevalent in our society may have played a large role here (Huang & Sun, 1995; Wu,1989): Students in general, and those in the lower level of the educational hierarchy in particular, are expected to conform and comply faithfully with demands emanating from authoritative figures such as school teachers and administrative personnel (to which group research assistants from a university aptly belong). That is, the fact that the subjects did not voluntarily engage in 3-D model construction may reflect some social-cultural constraints rather than cognitive inability.

Once they received clear instruction with regard to how the problems should be solved, both gifted and nongifted students were quite able to solve the problems by constructing 3-D mental models, as reflected in the null differences in overall performance accuracy. Gifted students, however, were able to solve the problems more efficiently than their nongifted counterparts in that on average they required less time to solve each problem than did the nongifted students. Such differences may suggest that, compared to nongifted students, gifted students may have an advantage in their capacities of spatial working memory (Shah & Miyake, 1996; Just & Carpenter, 1992). Constructing the mental model of a 3-D objects out of its orthographic projections no doubt requires a number of component processes. Having a greater capacity in spatial working memory could mean that the completion of some or all those component processes were speeded up. As a consequence, the gifted students were able to solve each problem with less time. It would be interesting for future study to provide measures of the capacity of spatial working memory for both the gifted and the nongifted students to bear out these speculations.

Another issue concerns the fact that we found clear evidence for *gender differences* in Experiments 2 and 3. Males seemed to spend less time in model construction and to have greater confidence in their judgments on 3-D structures than their female counterparts did in Experiment 2. Likewise, in Experiment 3, males yielded a higher accuracy rate in their responses.

Gender differences in spatial ability have been suggested by many researchers in the past (Harris, 1978; McGee, 1982). Maccoby and Jacklin (1974), for example, pointed out that gender differences in spatial ability first appear in early adolescence when sex roles become more salient; therefore, males and females are likely to engage in different activities and developing different interests and abilities (Nash, 1979). Other researchers have suggested that gender difference exist prior to adolescence. For example, there is evidence suggesting that boys are more accurate than girls in spatial representations, such as in constructing toy models of their classrooms and towns in kindergarten (Hart, 1979; Siegel & Schadler, 1977). One should be cautious, however, about drawing premature conclusions regarding the true relationship between spatial abilities and gender differences because, as pointed out recently by Geary (1996) and Voyer et al. (1995), their relationship may be far more complicated than has been suggested by earlier researchers. One main problem with previous studies, those with college students as subjects in particular, has been a lack of control of differences in the academic backgrounds, training, and experience of men and women (Newcombe, 1982). The present study was not designed specifically to examine gender differences. However, it would be interesting in future research to investigate possible gender differences in the gifted population. Such a comparison could avoid the pitfall of not being able to control factors that may confound or blur the true relationship between genders and visuospatial abilities.

It is important for the purpose of present study that the results we obtained with respect to differences in performance between gifted and nongifted students cannot be solely attributed to differences between sexes. That is why we included both male and female gifted (and nongifted) students as subjects for the present study. The results we obtained across three experiments were never the case that only gender differences existed while differences between the gifted and nongifted were totally absent. That is, whenever gender differences were found, those differences were always accompanied by differences in giftedness. It is therefore very clear that giftedness and gender differences were very distinct factors contributing to subjects' performance on the tasks used in the present study. How giftedness may be related to sex difference is in itself an interesting empirical question and awaits further research.

Finally, in light of the idiosyncratic selection process that each school uses to identify gifted youngsters, we need to consider how to more systematically identify some basic differences between gifted and nongifted students based on measures other than their academic performance. (Note that academic performance was the criterion used by the schools from which our subjects were recruited.) Some of these differences may be critically related to high-school students' abilities in solving visuospatial problems but may not be completely related to the criteria used to identify giftedness. It is very likely that one such difference entails spatial abilities, which have been implicated in mathematical and scientific thinking. A widely shared belief has been that an individual's scientific aptitude may be closely related to his or her ability to perform spatial reasoning. There is little doubt that the mastery of curriculum subjects such as mathematics and science in high school may require good spatial abilities (Geary, 1996; Benbow, 1988, 1992). However, there may be factors other than spatial abilities which contribute to an individual's excellent academic performance. These extra factors may have little to do with spatial abilities. What is needed is to determine in what ways and to what extent spatial abilities can help nourish a student's scientific aptitude. To obtain complete answers to those and related questions requires, we think, microgenetic probing of the mental structures and processes that are involved in solving visuospatial problems. In our judgment, investigating and understanding how an individual constructs 3-D mental models while viewing 2-D orthographic displays is a good direction to take in future research.

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資優生與非資優生解決視覺空間問題之心智模式比較

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摘　要

建構三度空間的心像模型是解答許多與空間相關問題的必要條件。在本研究中所進行的三個實驗中，我們檢驗資優與一般高中生所建構的立體心像模型是否有差異。實驗一中受試者首先看見兩張直角投射平面圖然後判斷第三張平面圖是否與先前兩張屬於同一立體物。結果顯示受試者對於解答具高複雜度之物體的作業有較多的困難。然而在沒有明確的指示下，資優生與一般生均無以建構策略解答相容作業的證據。實驗二中便明確要求受試者依呈現之平面投射圖建構所對應之立體模型。結果顯示資優生較一般生所需建構時間爲短，並且男生較女生所需時間爲短。實驗三考驗在建構歷程中進行心像旋轉的可能性。結果發現在花費約略相同的時間進行建構作業的情況下，資優生較一般生更能正確選出對應平面圖的立體圖型。同時，男生也比女生表現出較高的正確率。這些結果反映出，在明確的指示下，資優生較一般生表現出較佳的建構立體心像的能力。性別差異與資優之關係亦於文中加以討論。

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Interaction between Different Gender Students and Their Teacher in Junior High School Biology Classes

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Abstract

The purpose of the present study was to investigate how junior high school male and female students (23 males and 25 femals) interact with their biology teacher in classes. The results of teacher's interviews showed that the teacher described boys as aggressive, creative, and actively participated in class interaction more often than girls did. Classroom observation results indicated that boys answered four times as many to teacher-initiated questions than did the girls, and that boy's call-out responses to teacher's questions were 34 times more than that of the girls. In addition, teacher directed more questions to the boys than to the girls. In response to students' answer, the teacher was tending to restate or to clarify the answers, or to ask further questions. Moreover, the teacher gave boys more feedback than did girls; and the teacher occasionally gave boys comment to their answers, or negative feedback or no feedback at all. The impact of teaher's perception of students on different gender students' participation in classroom discussion was discussed in the article.

Key Words: gender differences, teacher-student interaction, junior high school biology classes

I. Introduction

Deboer (1984) and Fox (1976) reported that the junior high school years are the most critical period in the determination of gender role interests and differences in achievement between boys and girls in science and mathematics. Fox (1976) suggested that social factors can explain the lag in adolescent girls' interest in science. He further pointed out that the classroom itself serves as one area in which social roles in science are learned through interaction with teachers and peers. Classroom interaction seems to have a major influence on girls' interest in and career choices in science.

Since 1975, several research studies on gender-related differences in classroom interaction have been conducted in western countries. According to Good, Sikes, and Brophy's study (1973), boys interacted more frequently and aggressively with teachers than did girls; teachers were more likely to ask boys process questions and to ask girls product and choice questions. Boys received more attention than girls when they interacted with teachers (Leinhardt, Seewald, & Engel, 1979). Girls are often viewed as invisible members of the class (Sadker & Sadker, 1982). Moreover, Bean (1976) and Parsons (1979) reported that teachers interact more with male than female students in science class. Baird (1976) described males as being encouraged to be independent, aggressive, problem-oriented, and willing to take risks in social interaction. Females, in contrast, are more sensitive to nonverbal cues, less interested in problem-solving, relatively unwilling to take risks, and more yielding to social pressures.

In addition, researchers have indicated that teachers appears to be the persons who reinforce gender differences through the differential feedback they give to boys and girls (Dweck & Bush, 1976; Dweck, Davidson, Nelson, & Enna, 1978). According to the review done by Fennema and Sherman (1976), many studies have shown that students' attitudes toward mathematics are highly related to their experience with teachers. Dusek (1975) and Lockheed (1975) noted that teacher expectation has been demonstrated to have a large effect on students' achievement.

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In the review of the literature on gender-related classroom interaction given above, most of the studies were conducted at the elementary school level, and only a few of them at the middle school level. In addition, most of them examined general science or mathematics classroom interaction and rarely focused on biology classroom interaction. Therefore, the author was eager to learn whether these gender-related differences in classroom interaction are universal or whether they happen only in some specific school levels and/or specific subjects and/or in western countries. The purpose of this study was to examine the nature of and extent to which students differing in gender interact with their biology teachers in junior high school biology classroom settings in Taiwan. In addition, teacher interviews were conducted in order to get a better understanding of gender-related classroom interaction in this specific setting.

II. Methods

1. Subjects

A total of 48 students (23 male and 25 female students) from a junior high school seventh grade class were involved in this study. The academic achievement of these students was about average for seventh grade in this school. Laura (nickname) is the female teacher who was involved in this study. She obtained her B.A. in biology and M.A. in science education. The students were observed with respect to their interaction with their biology teacher (Laura) during seventh grade biology classes in the spring 1994.

2. Coding System

In order to analyze teacher-student interaction behavior, the author developed two coding systems to systematically categorize these behaviors: a teacher-initiated teacher-student interaction (TITS) coding system and a student-initiated teacher-student interaction (SITS) coding system. TITS contains types of teacher-initiated questions (four items), types of student responses (four items), correctness of students answers (five items), and types of teacher feedback (15 items). SITS includes types of student-initiated questions (four items), types of student responses (four items), and types of teacher feedback (13 items). The coding systems was tested for a semester, and the percentage of agreement of cross-coder reliability was about 0.88.

3. Procedure

Good and Brophy (1991) noted that looking for specific behaviors in the classroom is one way to minimize the degree to which our attitudes and biases will color what we see. Through classroom observation, we can know the extent of interaction that takes place between teacher and students. Therefore, the classroom observation method was used to measure the extent and nature of student-teacher interaction in biology classes. Classroom observation was conducted twice a week for one semester. In order to understand the reasons behind and obtain further information about the interaction observed in the classroom, an interview method (semi-structured and unstructured interviews) was applied. A series of semi-structured teacher interviews was conducted based upon specific gender-related classroom interaction behavior.

4. Data Analysis

Teacher-student interaction was recorded using a video recorder. Twenty-six videotapes of the interaction of 48 students with their biology teacher in biology classes were then transcribed into transcript from. Later, these transcripts were coded using the TITS and SITS coding systems. Finally, all of the coding data was analyzed using the SAS statistical Package. Teacher interviews were tape recorded and transcribed for further analysis.

III. Results

1. Teacher-Student Interactions

Teacher-initiated questions were coded as four items: process, product, procedure, and choice questions. The process question require an integration of prior knowledge, product question require brief facual answers, procedure question require a description of how to approach a task, and choice question require students to choose one correct answer from several choice. Results showed that of 355 teacher-initiated questions, 14.3% were procedure questions, 4.0% were process questions, 70.7% were product questions, and 11.0% were choice questions. Among student answers to teacher-initiated questions, 59.7% were call-out, 0.3% were open, 36.5% were direct, and 3.7% were by drawing lots. Student responses to teacher-initiated questions were 70.2% correct, 6.0% part-correct, 17.9% incorrect, 2.3% don't know, and 3.7% no response. There were 503 instances of teacher feedback given to students, which were 3.6% praise, 6.2% affirmation, 1.4% negative, 6.2% correction, 16.7% clarification, 4.2% expansion, 1.2% comments, 29.6% restated answer, 2.8% repeated questions, 2.2% hints, 9.0% further questions, 5.4% questioning answer, 3.2% ask others, 6.0% no feedback, and 2.6% more answers.

2. Boys' and Girls' Interaction with Teacher

Results showed that boys' and girls' participation in these middle school biology classes differed in several ways. Of 355 teacher-initiated questions, 79.8% were answered by boys, and 20.2% were answered by girls. Of the girls' 20.2%, 2.2% was from procedure questions, 1.7% was from process questions, 15.2% was from product questions, and 1.1% was from choice questions. Of the boys' 29.8%, 12.1% was from procedure questions, 2.3% was from process questions, 55.5% was from product questions, and 9.9% was from choice questions (Table 1). In short, boys answered more teacher-initiated questions than girls did, regardless of the type of question. Boys answered teacher-initiated questions about four times more often than girls did. The questions most often answered by both sexes were product questions, and the difference between the number of product questions answered by boys and girls attained a 0.05 significant difference level (χ^2=4.66, p<0.05). In comparing four types of teacher-initiated questions answered by boys and girls, the difference reached a 0.05 significant difference level (χ^2=7.74, p<0.05).

Student response patterns were coded as four items: direct, open, draw lots, and call outs, which are shown in Table 2. There were 355 student responses. Boys' answers to teacher-initiated questions were 58.0% call out, 0.3% open, 20.0% direct, and 1.8% draw lots. Girls' answers to teacher-initiated questions were 1.7% call-out, 16.3% direct, and 2.3% draw lots. Boys' responded with thirty-four times more call outs than girls did (boys: girls=206:6), reaching a 0.0001 significant difference level (χ^2=99.14, p<0.0001). The teacher directed boys to answer questions slightly more often than girls did (boys: girls=71:58), which also reached a 0.0001 significant difference level (χ^2=77.12, p<0.0001). Draw lot responses also reached a 0.0001 significant difference level between boys and girls (χ^2=14.34, p<0.0001).

There were 503 instances of teacher feedback (Table 3). The teacher directed 80.9% of this feedback to boys and 19.1% to girls (boys: girls=407:96). Boys and girls received respectively 2.8% and 0.8% praise, 4.6% and 1.6% affirmation, 1.4% and 0% negation, 5.0% and 1.2% correction, 14.9% and 1.8% clarification, 2.6% and 1.6% expansion, 1.0% and 0.2% comments, 24.6% and 5.0% restated answer, 2.2% and 0.6% repeated question, 1.8% and 0.4% hints, 6.9% and 2.0% further question, 4.0% and 1.4% questioning answers, 1.6% and 1.6% ask others, 5.7% and 0.2% no feedback, and 1.8% and 0.8% more answers. In fact, except for the ask others, the teacher gave boys more feedback of each type than she did girls. Regardless of gender, most of the feedback received from the teacher was of the restating answer, clarification,

Table 1. The Frequency of Types of Teacher-Initiated Questions Answered by Different Gender Students with Chi-square

	Male		Female		Total	χ^2
	f	%	f	%		
Procedure ques.	43	12.1	8	2.2	51	0.78
Process ques.	8	2.3	6	1.7	14	4.66*
Product ques.	197	55.5	54	15.2	251	0.95
Choice ques.	35	9.9	4	1.1	39	2.67
Total	283	79.8	72	20.2	355	7.74*

*p<0.05

Table 2. The Frequency of Types of Student Responses by Different Gender Students with Chi-square

	Male		Female		Total	χ^2
	f	%	f	%		
Call out	206	58.0	6	1.7	212	99.14***
Open	1	0.3	0	0	1	0.25
Direct	71	20.0	58	16.3	129	77.12***
Draw Lots	5	1.4	8	2.3	13	14.34***
Total	283	79.7	72	20.3	355	102.47***

***p<0.0001

Table 3. The Frequency of Types of Teacher Feedback Given to Different Gender Students with Chi-square

	Male		Female		Total	χ^2
	f	%	f	%		
Praise	14	2.8	4	0.8	18	0.05
Affirmation	23	4.6	8	1.6	31	0.67
Negation	7	1.4	0	0.0	7	1.80
Correction	25	5.0	6	1.2	31	0.01
Clarification	75	14.9	9	1.8	84	6.10**
Expansion	13	2.6	8	1.6	21	4.45*
Comments	5	1.0	1	0.2	6	0.05
Restated Answer	124	24.6	25	5.0	149	1.83
Repeated Question	11	2.2	3	0.6	14	0.01
Hints	9	1.8	2	0.4	11	0.00
Further Question	35	6.9	10	2.0	45	0.08
Questioning Answer	20	4.0	7	1.4	27	0.60
Ask Others	8	1.6	8	1.6	16	0.00
No Feedback	29	5.7	1	0.2	30	5.77*
More	9	1.8	4	0.8	13	0.94
Total	407	80.9	96	19.1	503	

*p<0.05, **p<0.01

and further question types. There were statistically significant differences between boys and girls for receiving clarification (χ^2=6.10, p<0.01), expansion (χ^2=4.45, p<0.05), and no feedback (χ^2=5.77, p<0.05). The teacher praised boys (2.8%) three times more often than she did girls (0.8%). The teachers affirmed boys (4.6%) three times more often than girls (1.6%). Only boys received negative feedback. Boys received comments and no feedback more often than girls did.

The types of teacher feedback given to students of different genders according to the correctness of their answers are described in the following. When male students answered questions correctly, most feedback received from the teacher was of the type restating answer (36.3%), clarification (23.3%), further question (10.3%), and affirmation (7.7%). For female students, most of the feedback given by the teacher was restated answer (33.3%), further question (12.1%), affirmation (12.1%), and clarification (11.5%) when the answers were correct. Regardless of gender, when the answer was partly correct, the teacher often gave correction or clarification. When the answer was incorrect, the teacher frequently gave correction, restated answers, and questioning answers. Correction and clarification were given to boys when they responded with "do not know". The feedback types of "ask other" and "repeated question" were given to girls when they answered "do not know". When students did not give any response to the teacher's questions, "ask other" and "comment" type responses were given to boys, and "repeated questions" and "ask other" type responses given to girls.

In short, the teacher only gave praise and affirmation feedback to students when their answers were correct, regardless of gender. The teacher only gave boys negative feedback when they answered incorrectly, and the teacher gave comments when their answers were either incorrect, don't know, or no response. The teacher also gave expansion and more answer responses to students when their answers were correct or partly correct.

A total of 26 biology class periods were observed during the semester, and only 13 questions were initiated by students. All of the student-initiated questions were initiated by boys, and consisted of 8 product questions, 3 procedure questions, and 2 choice questions. All of the questions were initiated by call-out. Most of the feedback given by the teacher was of the "given answer" and "affirmation" types.

3. Teacher Interviews

The teacher described her way of teaching biology as asking students questions and helping them to construct their own knowledge and solve problems. She focused on students' higher-order thinking, learning and problem solving ability. She described boys' learning style as focused more on understanding major concepts rather than memorizing everything from lectures and textbooks; in addition, boys are more flexible and creative, and can grasp ideas more quickly than girls can. Boys are more active and participate in biology classes more often than girls do. In contrast, most girls are more passive and participate in classes through their eyes and nodding heads. She also said, "Very often, boys are more creative thinkers than girls, especially when I ask students unusual or difficult questions. Boys are more aggressive, free-minded, and creative than girls in biology classes."

IV. Discussion and Conclusion

According to the results of our study, gender-related differences in classroom interaction did exist to some degree in this junior high school biology classroom setting in Taiwan, which indicates that gender-related differences do not just occur in some specific school levels and/or specific subject matter and/or in western countries. Our findings obviously demonstrate that boys and girls participated and interacted with the teacher differently in the biology classroom. First, males participated in more interactions than did females. The results indicated that boys answered teacher-initiated questions about four times more often than girls did. The teach directed boys to answer more question than girls. All of the student-initiated questions were initiated by male students. The teacher's descriptions of boys' and girls' potential for learning and participation in biology classes may provide an explanation for why boys were dominant in the classes. For instance, the teacher feels that boys are more flexible and creative, and grasp ideas more quickly than girls do. Boys are more active and participate in biology classes more often than girls do; in contrast, most girls are more passive and participate in classes through their eyes and nodding heads.

Boys tended to answer more teacher-initiated question by call-out, which supports the results of Brophy, Everton, Anderson, Baum, and Crawford (1981) that boys called out more answers to teacher-initiated questions. Boys responded to teacher-initiated questions with call-outs 34 times more often than girls did. A possible explanation for why the teacher allowed male students to control classroom discussion through call-outs may be that the teacher's perception that males are aggressive, creative, and free-minded,

ERIC

coupled with their high frequency of participation and responses, made this phenomenon seem acceptable.

Morse and Handley (1985) suggested that feedback is essential in learning new information and concepts, which in turn are critical in learning science. Regardless of gender, the feedback most often received from the teacher was in the form of restated answers, clarification, and further questions. Only boys received negative feedback, and boys received more comments and no feedback than girls did. The reason for giving only boys negative feedback was provided by the teacher: "A few boys in class try to get the teacher's attention by answering or asking questions inappropriately and without thinking." Our results are different from these of Dweck, Davidson, Nelson & Enna (1978), in which teachers often criticized female students more often than they did male students. Our findings clearly demonstrate that the amount and type of teacher feedback given to boys were different from that given to girls.

According to these findings, we propose that the teacher's perceptions of different gender students' learning and participation were related to the differences observed in the participation of the students, at least to some degree. This conclusion, which was discussed above, is based upon both the teacher's perception of boys' and girls' learning styles and participation, and on our classroom observation results. In addition, teacher-student interaction is not a one-way phenonmenon. It is indeed hard to say whether the teacher is the one who causes these differences or whether the students cause this differences, but we strongly suggest that the teacher does have some degree of impact on these gender differences, at least in directing boys to answer more questions, in letting boys make call-outs frequently, and in giving students differential feedback.

As science educators, what should we do? Based upon the Concerns-Based Adoption Model (CBAM) (Hall, 1987), I suggest that we should raise teachers' awareness of gender-related differences in classroom interaction during teacher education and inservice programs. Once they become aware this issue and its impact, we can provide them with more information about gender-difference-related teacher-student interaction and its influence on students and teachers. In particular, we need to help these teachers observe their own interaction with students and, through a self-reflective process, interact with students of both genders more equally. We hope that his process may produce more equal participation and interaction in the science classroom environment.

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不同性別國中生與生物教師之互動

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摘　　要

本研究的目的是探討老師與不同性別學生在國中生物課中的師生互動情形和原因。以教室觀察法和訪談法對國中生物課48位同學，其中有23位男生，25位女生和生物教師互動進行一學期的觀察研究。結果顯示男生回答問題約爲女生的四倍。男生回答問題較多以叫出答案方式且爲女生之34倍。老師指定男生回答較多的問題。男女學生得到之回饋多爲重覆答案，澄清和引申進一步的問題。男生比女生得到較多的回饋，且只有男生得到負面、批評和没有回答的回饋。老師認爲男生比較主動參與課堂的活動，男生比較常有創意性的回答。這些結果顯示男生比女生在生物課中互動頻率高。根據我們的教室觀察和訪談，我們發現老師對不同性別學生的看法對於不同性別學生參與有某種程度的影響。

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Biology Teachers' Knowledge Base of Instructional Representations

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Abstract

The purpose of this study was to identify the knowledge base that contributed to biology teachers' instructional representations. Classroom observations, interviews, and analysis of various related documents were collected data from four junior high school biology teachers. Analysis indicated that the teachers' knowledge base of instructional representations consisted of six major categories: knowledge of subject matter, students, curriculum, teaching media, contexts, and alternative representations. Each category in turn could be divided into several subcategories. The teachers integrated their understanding of all components of the knowledge base to represent subject matter for teaching. Additional information related to the knowledge base of expert teachers were also discussed.

Key Words: knowledge base, instructional representations, junior high school, biology teachers

I. Introduction

The purpose of science instruction includes facilitating students' understanding of science knowledge. Facilitating students' understanding involves many different activities, such as explanation, asking questions, responding to students' questions, developing tasks, and assessing what students understand. These activities emerge from a bifocal consideration of subject matter and students. To be a successful science teacher, one cannot have only an understanding of a particular concept, principle, or theory of science. In order to foster understanding, science teachers must also have the knowledge needed to generate representations of subject matter that will facilitate the development of understanding of science in their students. In Wilson, Shulman, & Richert's study (1987), Frank, a biology teacher, implied that a teacher had to represent the subject matter for students in 150 different ways.

The transformation of subject matter into forms that are comprehensible to students is the central intellectual task of teaching (Shulman, 1986, 1987). What kinds of knowledge do teachers need for developing and using effective instructional representations? Based on the assumption that much can be learned from studies of experienced science teachers, the purpose of this study was to identify the knowledge base that contributed to the effective instructional representations demonstrated by four exemplary biology teachers. By instructional representations, we mean a wide range of forms that may convey something of the subject matter to learners, including activities, questions, examples, and analogies (McDiarmid, Ball, & Anderson, 1989). The knowledge base is the framework that consists of several different types of knowledge.

II. Literature Review

Studies have shown that teachers' knowledge influences their instructional actions and, ultimately, impacts the learning that takes place in schools (e.g., Clark & Peterson, 1986). Studies of representations

27

frequently focus on the role content knowledge plays in determining the representations used. Researchers suggest that teachers' content knowledge does influence teaching activities. Gess-Newsome and Lederman (1995) selected 10 preservice biology teachers as subjects. Each teacher was asked to complete questionnaires and participate in a videotaped interview. The level of content knowledge was reported to have had a important impact on how content was taught. Teachers made a greater number of integrative connections among content topics that were part of their specialties than among those in other areas. Weak content knowledge affected the content taught in different ways; one teacher taught the topics in a superficial manner while another dropped the unit from the curriculum.

In Carlsen's (1991) two studies, analyses focused on daily lesson plans, transcripts of science lessons, and statistics on individual teacher and student utterances for each of four new biology teachers. A relation was found between the teachers' subject matter knowledge and their classroom discourse. When the content was familiar, teachers were more likely to encourage student participation in discourse. When the content was unfamiliar, they tended to discourage student participation in discourse.

Hashweh (1987) compared the teaching of experienced biology and physics teachers when they taught both biology and physics. Six teachers were asked about their subject matter knowledge in both biology and physics and to subsequently plan an instructional unit in both areas. In an unfamiliar subject area, the teachers generated superficial, inappropriate, or misleading representations, overlooked inaccuracies in the textbook, and failed to reorganize misconceptions. In general, the cross-assigned teachers lacked pedagogical content knowledge and subject matter knowledge, and this lack had an important effect on their instruction.

In these studies, subject matter knowledge included not only an understanding of the facts and concepts of a discipline, but also an understanding of substantive and syntactical knowledge. Substantive structures are the conceptual tools, models, and principles that guide inquiry in a discipline. Syntactical structures include a discipline's canons of evidence and proof, and rules concerning how they are applied (Schwab, 1978). Some authors (e.g., Hasweh, 1987) have suggested that the notion of subject matter knowledge should be broadened to include an instructional dimension. Shulman (1986, 1987) called this pedagogical content knowledge.

As Shulman (1987) observed and conversed with teachers, he found that student teachers developed a new type of content knowledge-pedagogical content knowledge that was enriched and enhanced by other types of knowledge: general pedagogical knowledge, curriculum knowledge, knowledge of learners, and knowledge of educational contexts. Pedagogical content knowledge is defined as "a blend of pedagogy and content which includes an understanding of how the topics of instruction are organized, represented, and adapted to students, and presented in the classroom context". Pedagogical content knowledge also includes the ways of representing and formulating the subject that make it comprehensible to students and an understanding of what makes the learning of specific topics easy or difficult (Shulman, 1986). This knowledge develops in a cyclic process in which teachers comprehend, transfer, instruct, evaluate, reflect, gain new comprehension, and transfer again (Shulman, 1987).

Pedagogical content knowledge enables teachers to transform content knowledge into forms to help students to learn. Based on Shulman's idea of pedagogical content knowledge, many researchers have explored teachers' transformation of subject matter for teaching. After interviewing eight fifth-grade mathematics teachers, Marks (1990) presented a description of pedagogical content knowledge in mathematics. He suggested one framework for studying pedagogical content knowledge consisting of four components: subject matter for instructional purposes, students' understanding of the subject matter, media for instruction in the subject matter, and instructional processes for the subject matter.

Based on a constructivist view of teaching and learning processes, Cochran, DeRuiter, and King (1993) proposed a definition of pedagogical content knowing: "a teacher's integrated understanding of four components of pedagogy, subject matter, students' characteristics, and the environmental contexts of learning" (p. 266). They placed more emphasis than Shulman did on the necessity of understanding of students and the social, political, cultural and physical environmental contexts in teachers' pedagogical content knowing. The researchers emphasized knowing as an active process of learning how to teach.

Geddis, Onslow, Beynon, & Oesch (1993) described two student teachers' attempts at teaching chemical isotopes. The two case studies were based on a variety of audio-recorded and transcribed interviews with the student teachers and their cooperating teachers and on field notes of their classroom teaching. In the course of analysis, examples of four distinct categories of pedagogical content knowledge were articulated. Knowledge of learners' prior knowledge, effective teaching strategies, alternative representations, and curricular saliency were found to be important components of pedagogical content knowledge.

These studies (Cochran, DeRuiter, & King,1993; Geddis, Onslow, Beynon, & Oesch, 1993; Marks, 1990) indicated that pedagogical content knowledge was central to teachers' work and enabled teachers to transform subject matter knowledge. Most of these researchers employed Shulman's idea to articulate the concept of pedagogical content knowledge by exploring knowledge growth in students teachers. They emphasized that the meaning of teaching is context-dependent, thus requiring the collection of data in natural science classroom settings.

Studies on teacher knowledge have shown that experienced teachers develop a knowledge base over time. Leinhardt and Greeno (1986) described teaching as a complex cognitive skill in which teachers built up a knowledge base of complex schemata for teaching. Experienced teachers had better schemata than novice teachers. Berliner (1987) suggested that teachers developed complex cognitive schemata through planning, interactive teaching, and reflecting. As they gain more expertise, they become more able to draw upon their knowledge and experience. It seems that expert teachers can provide rich information which can help us build a knowledge base for teaching.

The Search for Excellence (Penick & Yager, 1983) and similar studies that have caused considerable excitement and motivation among teachers. This study followed this line of research to explore the knowledge base of representations in exemplary teachers in a real teaching situation.

III. Methods

Interpretive methods described by Erickson (1986) were used in this study. Multiple qualitative data gathering methods and triangulation were employed to enhance the validity of the findings.

1. Selection of Teachers

The four exemplary teachers for this study were selected from a list of candidates of exemplary biology teachers as nominated by science education experts and scholars in Taiwan. An observation of each potential participant's classroom teaching was conducted to select candidates who demonstrated expert teaching characteristics. "Criteria of Excellence: Biology Teachers of Junior High School" (Lin, 1994) presents the expert characteristics of biology teaching used here in selecting the teachers. The criteria, including teaching style, professional skills, teaching environment, community involvement, and professional development, were established in previous studies (News & Views, 1989; Penick, 1984; Yager, 1986). The selected exemplary teachers and the school administrators were approached to gain their cooperation.

2. Context and Participants

Four female teachers, Amy, Betty, Christine, and Debra, had taught biology in junior high school for 26, 13, 13, and 18 years, respectively. Both Amy's and Betty's schools were located in Taipei city, Christine's in Taipei county, and Debra's in Keelung city. One of each teacher's classes was observed. There were from 38 to 48 students in the participating classes.

The teachers had professional training in biology. Amy had received her Bachelor's degree in health education. Betty, Christine, and Debra had obtained their Bachelor's degrees in biology. They all had earned some Master's level credits in biology.

All four teachers had won awards for outstanding achievement. For instance, Amy had won an Award for Outstanding Achievement at the Taipei Municipal Science Fair. Betty had won an Annual Outstanding Teachers' Award. Christine and Debra had each won an Award for Outstanding Achievement at the Taiwan Provincial Science Fair.

3. Data Collection

Data were collected mainly by means of classroom observations, interviews, and document reviews. Classroom observations were performed for at least 28 lessons over a duration of 10-12 weeks. All observations were made from a seat at the back of the classroom. The teachers were interviewed before or after each classroom observation with respect to their instructional representations. All observations and interviews were videotape or audio tape recorded. Related documents, including teaching aids, outlines, record sheets, and tests, were preserved by means of photocopies or photography.

Six students from each participating class were interviewed by the researchers at the end of the observations. A stratified random sampling technique was used to ensure that two students from above-average, average, and below-average achievement groups were selected in each class. The interviews with each student took about an hour. These students provided information on their perceptions of the manner

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in which biology teaching and learning occurred during the study.

4. Data Analysis

The data base consisted of field notes and transcriptions from observations, interviews, and documents. Vignettes were taken from field notes and transcriptions to describe the teaching practice and tentative assertions of the practice. These vignettes were discussed with the teachers, regularly throughout the study, to confirm the meaning of their behavior. The four teachers were also asked to comment on any ideas they believed misrepresented or were incomplete. All the vignettes were classified and coded to address the following research question: What kinds of knowledge do teachers use to transform subject matter? Vignettes were classified by researchers into five major categories: alternative instructional representations, knowledge of subject matter, knowledge of curriculum and teaching media, knowledge of students, and knowledge of the teaching context. Within each category were many subcategories, such as forms of instructional representations, models of using representations, and contexts of using representations in the category of alternative representations. All the vignettes were examined for trends and frequency. Tentative hypotheses about the knowledge base of content representations were formed. Specific trends were explored, and more concrete hypotheses were formulated and tested subsequently, using coded data obtained from different data gathering methods. Contradictory data were sought to help in revising the hypotheses. Reliability checks for coding were conducted by a research team of two science educators and four exemplary biology teachers in junior high schools.

IV. Findings

Several different types of knowledge that teachers used to form instructional representations emerged when the data from the four teachers were analyzed. Teachers' knowledge of subject matter, students, curriculum, teaching media, contexts, and alternative representations were found to influence teachers' transformation of subject matter. Within each category, there were many different subcategories which existed simultaneously as a knowledge system (Fig. 1.). Extensive knowledge helped them to effectively generate multiple instructional representations. Findings are presented according to the types of knowledge.

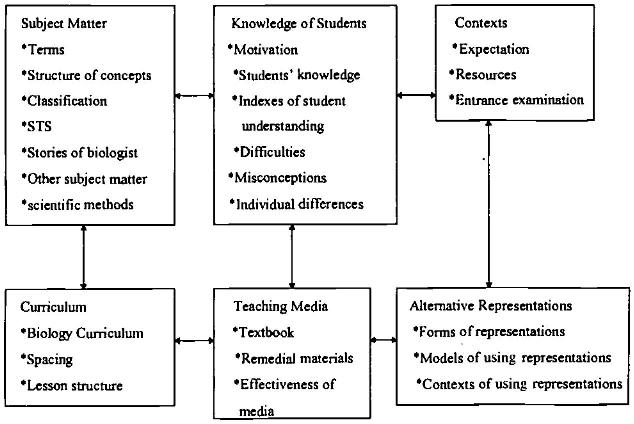

Fig. 1. Structure of the knowledge base of instructional representations.

1. Knowledge of Subject Matter

Subject matter was the raw material for representations. The teachers' subject matter knowledge included biology terms, the structures of concepts, classification, science-technology-society issues, real life stories of biologists, other related subject matter, and scientific methods.

A. Biology Terms

The biology terms included names of organisms (e.g., frog, amphibian), terms of biological structure (e.g., cell membrane, nuclear), and terms of biological events and behavior (e.g., metabolism, reproductive behavior). Most of these terms were experiential terms that could be observed or manipulated by their students. Some were more abstract, such as probability and gene. Biological terms used were basic tools for communicating between biologists. Some of these terms (e.g., classification, evolution, consumer, producer) are also used in everyday life or other disciplines but have different definitions and meanings. These teachers' students were easily confused when they tried to learn these terms. The teachers demonstrated strategies which could help students to learn. For example, Betty provided bone structures of butterflies and birds to clarify that they belonged to two different groups although they all had wings.

B. Structures of Concepts

Structures of concepts were higher level knowledge in biology. Principles and rules (e.g., Mendel's principle of genetics, Darwin's natural selection) were examples of the structures of concepts. The teachers also used other connections to organize different concepts, such as comparison (e.g.,comparison between mitosis and meiosis), anthropomorphism/teleology (e.g., the purpose of meiosis is to generate gametes), history/ development (e.g., the life cycle of the frog), structures and function (e.g., the function of the beautiful petals of a flower is to attract insects which act as pollenators), and interaction between plants, animals, and environment (e.g., food chain, ecosystem). These structures helped students to connect learned concepts.

C. Classification

Taxonomic classification is an important topic in biology. The teachers presented only one well-defined schema and provided typical examples of each category. They never mentioned the difficulty of classifying species that had characteristics of more than one category. The reason for this was that the teachers wanted to simplify the content and the concept did not appear in the textbook. The teachers also asked their students to classify according to teacher-set criteria. For example, Betty asked her students to classify animals into two groups according to wing structure. According to Betty, this classification helped students to organize the complex facts into a system.

D. Science-Technology-Society Issues

The teachers mentioned science-technology-society issues related to different topics. Moral issues of genetic technology and pollution related to nuclear energy were commonly included in lessons. The teachers tried to show their students that knowledge of biology was not unconnected to daily life. Amy said, "Through the discussion of the application of genetic technology, students had an opportunity to think over the relationship between human beings and science."

E. Stories of Biologists

Examples the teachers included in their classes included the development of Charles Darwin's evolutionism, the experiment designed by Louis Pasteur to find bacteria, and the story of the "Father of Genetics", Gregor Mendel. The teachers believed these stories could provide students with a social and cultural context, an understanding of the development of science concepts, and a human face for science. After introducing the story of Darwin, Debra said, "The story could tell students that evolution was not discovered suddenly. It took a long time to develop, and it interacted with the existing social values." The students always showed great interest in personal stories about famous scientists.

F. Other Subject Matter

Genetic probability requires knowledge of mathematics. Energy transfer in the organism involves physics. The teachers also mentioned many chemical terms and chemical reactions in teaching photosynthesis.

G. Scientific Methods

Observation, manipulation, and integration were the major process skills the teachers emphasized in their classes. Most of the laboratory classes proceeded in a manner that followed the teachers' instructions and tested a preexisting hypothesis. Sometimes, Christine provided students with opportunities to design experiments. Logical reasoning, including induction and deduction, was presented in both laboratory classes and teacher interpretations.

The teachers' extensive knowledge of subject matter helped them to identify important objectives of biology instruction. This knowledge helped them to explain the facts, concepts, structures, and methods of biology more clearly. In addition, their knowledge of other subject matter helped them to understand biology more deeply and to translate the content in a way that was more comprehensible to their students. During interviews, most of the students of these four teachers indicated that their teachers had intensive subject matter knowledge which they used to explain the concepts and answer student-initiated questions. One of Debra's students said, "Our biology teacher is just like an encyclopaedia, knowing everything about biology."

2.Knowledge of Students

The teachers' knowledge of how students learn led them to select different teaching strategies. Motivation, students' knowledge, indexes of student understanding, learning difficulties, common misconceptions, and individual differences were major subcategories of knowledge of students.

A. Motivation

The teachers used different forms of motivation to encourage their students to participate in learning. These strategies were based on the knowledge that motivation is a prerequisite for effective learning. Motivation took the form of establishing a pleasant learning climate, giving praise to the students, relating science to students' life experience, and arranging an appropriate degree of difficulty for learning. They favored different strategies. Giving praise and relating science to life experience were apparent in Amy's and Debra's classes. Betty and Christine favored manipulating questions to encourage their students to participate in learning.

B. Students' Knowledge

The teachers were concerned about how much knowledge and life experience, and how many reasoning skills their students had. After this information was acquired, the teachers could provide opportunities for students to relate the new content to the old content. The teachers reviewed related topics and experimental process skills learned in earlier lessons or in elementary school. They provided examples that were familiar to students to facilitate their learning of abstract concepts. The teachers also indicated that some learning difficulties came from the students' lack of adequate formal reasoning abilities; learning difficulty in genetics was a case in point.

C. Indexes of Student Understanding

The four teachers all emphasized teaching based on developing understanding. They used monitoring skills such as tests, informal quizes, encouraging students to ask questions, calling upon students to explain or clarify their answers, and eye contact to diagnose learning difficulties.

In whole-class activities, the teachers employed different strategies to monitor students' understanding. Eye contact seemed an effective and economical way to detect when something was wrong between themselves and their students. They could easily tell from students' behaviour, gestures, and facial expressions if lessons were not clear. They also used other strategies to diagnose students' learning. Amy always used an oral test strategy. Betty gave an informal quiz that took about 5-10 minutes at the end of the class period. Christine interviewed students when the class was over, and she also used an informal quiz to identify students' difficulties. Debra frequently encouraged her students to ask questions. Sometimes Debra spent 30 minutes of a 50 minute lesson discussing student-initiated questions.

During laboratory activities, the teachers all moved around to groups, reinforced the positive aspects of techniques, and identified instances of incorrect techniques. They all regarded these interactions as useful for gaining feedback from their students and for giving clarification and encouragement to students regarding their understanding.

Almost all the students interviewed commented on the above monitoring strategies as a positive characteristic of their teachers' instruction.

D. Learning Difficulties

The teachers were aware of difficulties commonly encountered in learning biology. The common characteristics topics difficult to learn were their complexity, large number of terms, abstract nature, and the fact that they were not observable with the naked eye. Most of these topics were within the area of genetics, cell biology, and evolution. Therefore, the teachers used illustrations, examples, drills and practices, and discussion to help students overcome difficulties. Each teacher had her own favorite strategies for this situation. Amy favored using examples. Betty usually selected illustrations. Christine related science to general knowledge. Explanation was the principal strategies used by Debra.

E. Common Misconceptions

The teachers were aware of the usual misconceptions that students tended to have. Thus, they could diagnose and remedy these misconceptions effectively. They also indicated that the possible sources of misconceptions were teachers' representations and common terms; they sensed that students over generalized from examples or facts. The teachers reflected on their representations, indicated differences between science concepts and common sense, and provided contradictory examples to help students understand. When interviewed, the students typically responded with statements such as: "The teacher seems to know every place where we will make mistakes. She points it out and really helps you understand."

F. Individual Differences

The teachers' knowledge of individual differences enabled them to select different representations to help students to learn. The stategies these four teachers used in this regard had similar features. In whole-class activities, students were encouraged to take part in class discussion. Each teacher sought answers from the weaker students though they were not volunteers. In group activities, groups which completed their work before others were given additional work; meanwhile, the teachers helped the slower groups. All four teachers encouraged peer cooperation in group activity by asking more able students to assist others.

The teachers suggested off-curricular activities for students who had special interests; a simple experiment was the activity suggested most often. Betty also encouraged students to watch related TV programs. Debra always introduced reference books and challenged students to discover through reading. The

ERIC

teachers gave feedback to students for antecedent kinds of behavior. Low-achieving students received limited cognitive-level help and no content modification; the teachers focused on behavior correction for this group.

The students provided their perceptions of the classroom climate in interviews. The general impression was that biology was one of their favorite classes in seventh grade, and that these teachers made learning interesting and easy. All the students perceived a high level of teacher support. One of Amy's students perceived that the teacher was kind and willing to support them. One student said that Betty was enthusiastic in providing opportunities to learn. One of Christine's students felt that Christine was just like a friend, always listening patiently to them. One student in Debra's class said, "I feel comfortable and proud when I ask questions. Debra doesn't make you feel stupid."

3. Curriculum Knowledge

A. Biology Curriculum

In the four classrooms, the instructional content was defined by the textbook. The teachers included all the concepts, activities, and questions; they had few opportunities to alter the existing pattern. However, they added appropriate content, ordered the sequence, linked concepts related to different topics and lessons, and selected or generated the needed teaching media or activities to help students learn the concepts and to compensate for the inadequacies of the textbook.

B. Spacing

The spacing of lessons followed the syllabus established by all biology teachers in their particular schools. Content was always presented on time or more likely late according to the teacher's preexisting outline. If the content was presented late, other class time was arranged to teach the remaining content.

C. Lesson Structure

The teachers structured their 50- minute lessons in a manner that began with review, followed by an introduction and extensive interpretation, and ended with a conclusion.

4. Knowledge of Teaching Media

A. The Textbook

The teachers were familiar with the intended objectives, content, and structure of the textbook. They identified improprieties and analyzed the learning difficulties of the textbook.

B. Remedial Materials

To remedy the lack of appropriate textbook content, the teachers designed or presented different materials. These materials included pictures, films, handouts, and specimens. Most of their students recognized the value of such teaching media. Nancy, one of Amy's students, said, "Pictures or films tell you the real things that happen in nature which you cannot learn from the text."

C. Effectiveness of Teaching Media

The teachers understood the advantages and limitations of using teaching media to enhance students' learning. The teachers indicated that the teaching medium provided students with rich information and concrete experience so as to relate the facts and concepts needed for meaningful learning. Betty said, "Pictures and films can provide students with more information than can explanations. Visual learning is more concrete than audio learning."

The media used also had limitations. The teachers indicated that some students were confused by overly complex facts, and that others were distracted by some animated materials and did not pay attention to key points. Amy said, "Media materials sometimes do not help students learn because there is too much to handle at one time." Debra said, "Some students are only interested in manipulating the materials and do not learn concepts."

5. Contextual Knowledge

A. Expectation

Expectations held by society, the school, parents, and students influenced the teachers' roles. The expectation of high achievement in examinations influenced their instructional emphasis, test frequency and test contents. School administrators, colleagues, parents, and students thought that a clean, orderly, and quiet classroom environment was a prerequisite for effective learning. These ideas about prerequisites for effective learning made Betty feel pressured when she implemented new representations that were student-centered and put more responsibility on students for their own learning. She always needed to explain how the new activities could help students learn important things and had to persuade her students to cooperate with her. Students' images of a good biology teacher as someone who knew everything about the subject matter made Debra act like a knowledgeable scholar who knew all the answers or knew how to find answers to questions raised by her students.

B. Resources

The hardware and software used inside and outside the classroom had an important impact on the way in which all the teachers used materials and media. They knew where to get and who would provide resources for teaching, and they could learn new methods and knowledge which they could use to improve their instruction when they felt the need. University libraries, science museums, educational information centers, botanical gardens, zoos, and national parks were the places they or their students usually visited. All four teachers built good relationships with university professors, teacher center consultants, and colleagues who could provide assistance and suggest alternatives when asked for help in solving teaching problems.

C. The Entrance Examination for Further Study

After finishing study in junior high school, most students take an entrance examination for further schooling in senior high school. Biology is one of the important subjects included in the entrance examination. Helping students to pass the entrance examination has become the dominant goal of secondary education. During interviews, most of the students agreed that helping them to pass the entrance examination was one of the important goals of secondary education. Pressure due to the entrance examination influenced the ways in which all four teachers taught the entire textbook because the textbook was the major reference used to prepare the examination. The pressure due to the entrance examination tended to restrict each teacher's role and make them more like a textbook interpreter than a curriculum designer. The teachers also focused on the content of previous entrance examinations.

6. Knowledge of Alternative Representations

Within the teachers' knowledge of alternative representations, there were forms of representations, models of using representations, and contexts of using different representations. The teachers' extensive knowledge of alternative representations provided the bases for their teaching models and teaching flexibility. Almost all the students interviewed commented on the availability of alternative representations as an important factor which helped them understand.

A. Forms of Representations

Several different forms of representations were demonstrated by the teachers. The forms of representations were classified into three groups: teacher-centered, teacher-student-centered, and student-centered. In the teacher-centered form of representation, the teacher was the major actor. The teachers communicated knowledge using words, analogies, metaphors, cause and effect interpretations, examples, and definitions. They also communicated knowledge by using words accompanied by pictures and specimens. There were illustrations and demonstrations. In the teacher-student-centered form, the teachers and their students had frequent interaction and communication. Based on whether questions were open or closed and on students' reactions, this form of representation was divided into two subcategories: question and answer guidance and discussion. In the student-centered form of representation, the students were the major actors. Manipulation, simulation games and homework were the components of this form. The predominant forms of representation were question and answer guidance, discussion, cause and effect interpretation, manipulation, illustration, and demonstration.

B. Models of Using Representations

The teachers usually began with a teacher-centered form to introduce a new concept, followed by a teacher-student-centered or student-centered form designed to help students thoroughly understand. If the students were familiar with the concepts, for instance, classification and food webs, the teachers began by choosing the form in which their students could actively participate, for example, a discussion or a simulation game.

In laboratory classes, the teachers first interpreted the goals and procedures of the experiments. Student manipulations occupied the middle period of each class. Then, the class ended with discussion or question and answer guidance.

C. Contexts of Using Different Representations

The teachers used different representations in different teaching contexts. These were grouped according to forms of representations.

An **analogy** or a **metaphor** was presented when the four teachers used a familiar concept or subject to help the students understand an unfamiliar and abstract concept. These analogies and metaphors always appeared in a one- or two-sentence form. For instance, Betty explained: "A pollen tube can transfer sperm just as a water tube can transfer water. They both have the function of transportation."

A cause and effect explanation was used when

ERIC

the teacher wanted to explain the logical relationship between two phenomena or when a teacher or student raised a question.

An **example** was given when the teacher wanted to provide concrete or specific information about a rule, principle or abstract concept.

A **definition** was usually presented to summarize the meaning of forward representations. A **definition** was also used as an advanced organizer.

Illustrations and **exhibitions** combining audio/ visual learning were presented when the teachers taught abstract concepts, complex procedures, and the morphosis and structure of biology. For example, Betty used about 70 pictures to help explain the stages of mitosis.

A **demonstration** was usually used to teach an experimental process skill. When teaching "microscopy", the teachers demonstrated the correct procedures for using a compound light microscope, and then asked students to manipulate a microscope by themselves.

A **question and answer guide** was used when the teacher wanted to divide a complex difficult question into a series of easy-to-answer questions. This was a small step strategy by means of which the teacher could easily guide and monitor each stage of student learning.

When their students had enough prerequisite knowledge, the teachers considered the use of **discussion**. The teachers invited students to participate in discussion which applied concepts in solving a new problem.

Student manipulations were the major activities of laboratory classes. Students were always grouped. There was a set of materials or devices to be handled by each group.

Simulation games were used when the four teachers presented concepts that involved complex interaction and could not be observed for a short time. Meanwhile, the teachers wanted their students to actively participate in the learning process. When teaching "food webs", Christine asked her students to play the roles of organisms, such as producers (e.g., plants, microorganisms), consumers (e.g., lions, birds),and decomposers (e.g., fungi, bacteria) in the environment. Then, she asked her students to connect threads to the organisms to complete the food web.

When the teachers wanted to included outside-of-class learning time, they assigned **homework**. Homework always consisted of independent study, such as completing an experiment report or watching a related TV program.

V. Conclusion

Pressure due to the entrance examination tended to influence the way in which all four teachers taught the material in the entire textbook. The content of the curriculum was based on the textbook. The teachers insisted that it was important to facilitate students' understanding by providing different instructional representations, but they did not put emphasis on repeating exercises and memorization of facts. Investigated were the kinds of knowledge the four teachers used to communicate knowledge to students. Interviews, observations, and related documents were used to collect data. Several different types of knowledge that the teachers used to form instructional representations emerged from analyses of the data for these four biology teachers. The teachers' knowledge of subject matter, students, curriculum, teaching media, contexts, and alternative representations, which existed simultaneously as a knowledge system, influenced the teachers' transformation of subject matter. It appeared that they had developed a complex schema for teaching as Leinhardt and Greeno (1986) proposed. All of them also seemed to have the mental scaffolding characteristic of experienced teachers (Peterson & Comeaux, 1987).

Subject matter formed the content of the teachers' representations. The teachers' subject matter knowledge included substantive and synthetic structure of a discipline (Schwab, 1978). Their understanding of subject matter far exceeded the content of their representations. All four teachers indicated that the subject matter they had learned during teaching was especially related to science-technology-society issues, the everyday life of students, stories about scientists and concrete knowledge. This kind of knowledge enabled the teachers to help their students relate biology knowledge to their everyday life experience. This result seemed to be similar to the finding of other studies (Hauslein, Good, & Cummins, 1992; Lederman, Gess-Newsome, & Lantz, 1994) that teachers reorganize and reconstruct their knowledge of the complex, huge, and yet loosely-organized subject matter needed for teaching.

Knowledge of how students learned led these teachers to consider the kinds of learning opportunities that needed to be provided. All the teachers had extensive knowledge of how their students learned. Most of this knowledge came directly from their own teaching experience.

Knowledge of curriculum and teaching media enabled the teachers to arrange proper learning activities. These teachers were familiar with the objectives, content, and structure of the textbook. They ordered the sequence, selected materials and media, and understood the effectiveness of materials and media.

Knowledge of alternative representations included not only various forms of representations, but also the correct time to use them and the proper reasons for using them. These were all important components of the knowledge possessed by these experienced teachers. These findings further clarify the concept of pedagogical content knowledge. The extensiveness of these teachers' knowledge of alternative representations enabled them to form their own teaching routines, and it also enabled them to demonstrate teaching flexibility in their individual circumstances.

The teachers had rich resources to draw from in learning to teach. Personal learning, teaching experiences, textbooks, other teachers, volunteer worker training, inservice training, university professors, library services, and students' response were all probable resources the teachers could draw from in acquiring a knowledge base. The results demonstrated that context knowledge played an important role in the teachers' ability to represent knowledge, similar to the suggestion made by Cochran, DeRuiter, & King (1993). The teachers probably learned how to teach through reflection on many years of teaching. Their knowledge construction involved not only self-organization, but also a social process. All four teachers were socialized into practices of school science teaching and the ways of knowing. Social culture provided conditions for these teachers to construct personal meanings. Sometimes, the teaching context restricted the teachers' instructional representations; at other times, it worked to facilitate or support the teachers' actions.

The teaching strategies they used often were quite different although they each had an intensive knowledge base of instructional representations.. When interviewed, most of their students commented on these strategies as a positive characteristic of each teachers' instruction.

The time limitation was a common difficulty all four teachers encountered. For example, Betty said, "I have spent much off-duty time forming representations to help my students understand. Generating a representation takes a lot of time. I renew representations slowly although there is a need for change."

All four teachers paid much attention to average-achievement students in a classroom with about 45 students. The teachers suggested extra-curricular activities for high-achievement students. Low-achievement students were not involved in real learning, and the teachers focused on behavior correction for this group. There is a need to provide better support for teachers so that they can more effectively help these low-achievement students learn.[1]

The data suggest that science teachers should be provided with an extensive knowledge base, including knowledge of subject matter, students, the curriculum, teaching media, the contexts, and alternative representations. Teachers should integrate the different categories of knowledge in their teaching. These are essential elements of subject matter for the teacher education curriculum.

These teachers have a wealth of ideas about instructional representations. The knowledge that expert teachers have should be shared with all those who are learning to teach. Further studies should be conducted with different teachers, research methods, and subject matter to enrich the knowledge base of instructional representations.

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生物教師教學表徵的知識基礎

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摘　要

本研究的主要目的是探討四位優秀的國中生物教師於教學中，將生物科學知識轉形爲不同型式的教學表徵以幫助學生學習生物時，所需要的知識類別。本研究以教室觀察、教師訪談、學生訪談、以及文件收集的不同方式收集資料。全程皆輔以錄音與錄影以便事後分析。研究結果發現教師具有豐富的知識以爲形成教學表徵的基礎，這些知識依研究者的分析可區分爲六大類，他們分別是於關於：(1) 學科專門知識的知識，(2) 學生與學習生物知識的知識，(3) 生物課程的知識，(4) 生物教學媒體的知識，(5) 生物教學情境的知識，(6) 教學表徵的知識。每一類別的知識又包括數種次類別的知識，這些知識互相交錯重疊，互相影響，形成一知識體系，這種知識體系是教師形成有效的教學表徵的重要基礎。此研究結果可以幫助我們進一步的了解專家教師教學知識的特性，並爲科學教師與科學師資培育者之參考。

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Understanding of the Nature of Science of Senior High School Students'

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Abstract

An understanding of the nature of science has become an important component of scientific literacy and the learning outcome of science education. This paper aims to report high school students' understanding of the nature of science based on the responses to the Understanding of the Nature of Science (UNOS) Scale. 15 students were interviewed and 1670 students were administrated. It was found that the students in the study had adequate understanding of the nature of science with average scores higher than the UNOS scales' mid-score, and that they believed more myths regarding scientific methods and knowledge than they did regarding scientific enterprise. Analyses of interview data revealed that the definition of science held by students was closer to that of physical science than to biological science, and that they had difficulty in understanding the difference between theories and laws. Moreover, interviews showed that they did not have an over-simplified view of scientific method, and that they insisted that scientists should lead an ideal life with, more or less, pure internal motivation and without external influence. As to the nature of the scientific method, some students showed high respect for the scientific method and believed that empirical data had inherent meaning. They also held that scientific observations and reports were nothing but an exact and uninterpreted document. As to the nature of scientific knowledge, some student believed myths concerning universality, ontological reality, and absolute truth. As to the nature of scientific enterprise, most students were not well informed of the nature of modern scientists.

Key Word: the nature of science; the nature of scientific knowledge; the nature of scientific method; the nature of scientific enterprise

I. Introduction

Scientific literacy has been accepted as a central goal of science education, and one important component of scientific literacy is the need for individuals to have an adequate understanding of the nature of science (American Association for the Advancement of science [AAAS], 1989; Matthews, 1994). Therefore, the development of an adequate understanding of the nature of science has been convincingly advocated as a desired learning outcome of science education by many science educators and institutions (AAAS, 1989; Martin, 1972; National Science Teachers Association [NSTA], 1982; Robinson, 1968). Moreover, worth noting is the nature of science has been included as an important curricular objective in the British national curriculum and in the National Science Education Standards in the U.S. (Department of Education and Science and the Welsh Office, 1989; National Research Council, 1996).

Unfortunately, school science usually misrepresents the image of science in textbooks and teaching, in which an authoritarian image of science has been perpetuated (Duschl, 1988). This view of science is impersonal and incomplete, representing scientific knowledge as absolute truth and as a final form, in a sense without involving the human voice and argumentative struggles (Sutton, 1996). This distortion of the image of science may not only block realistic understanding of what is science' and what is about science', but also hinder the development of positive attitudes toward science.

The findings reported in this paper are a part of a body of research on the development and validation of an instrument, Understanding the Nature of Science Scale (UNOS). The processes of development and validation, and the evidence of reliability and validity for UNOS were published in aother paper (Lin, 1996).

This paper aims to document the students' understanding of the nature of science found in the course of instrument development.

1. The Nature of Science

The nature of science, as a fruitful product based on research over the past decades in the fields of the history of science, the philosophy of science, the sociology of science, and other metasciences, refers to a realistic and complete view of theory invention, change, testing, and acceptance/rejection in science. The prevailing image of science is a manifestation of the philosophies of science developed during the first half of the twentieth century, that is logical empiricism and positivism. This tradition, commonly referred to as The Received View on Theories, continues to enjoy wide acceptance, while logical empiricism and positivism were rejected in the 1960s under intensive criticism from many recent philosophers of science (Suppe, 1977). Decades later, the Received View remains in school science education. McComas (1996) recently proposed ten widespread and enduring misconceptions held by students regarding the nature of science. He attributed the myths about science to the lack of philosophy of science content in teacher education programs and superficial coverage of the nature of science in science textbooks used in the primary and secondary schools.

The Received View of the philosophy of science held by logical positivism and empiricism clings to Reichenbach's introduction of the phrases "context of discovery" and "context of justification", which mark the distinction between the way a statement of scientific knowledge is discovered and the way in which it is presented, justified, and defended (Suppe, 1977). Two scientific methods, alleged to be associated closely intensively with these two contexts, are induction for the discovery of scientific knowledge and hypothetico-deduction for the justification of scientific knowledge. By means of these two scientific methods, true scientific knowledge is expected to be achieved.

However, the problem of induction has dealt with in the 18th century by Hume. He found that inductive generalizations can not be justified on the basis of experience without circularity, which remains the major problem yet to be solved for inductionism. Hypothetico-deduction used for justification has two variants, verification and falsification. The former is logically implausible due to the fact that it includes the common fallacy of affirming the consequent (Hemple, 1966) while the latter fails to determine whether the theory in question is false or the auxiliary hypotheses or both are false in a single test. Even with employment of multiple tests, the problem of hypothetico-deduction remains (Ariew, 1984).

Beginning in the early 1960s, a number of philosophers of science proposed a different, and probably more appropriate, image of science based on and supported by empirical study of real life of science or scientists. Historical study no longer regards scientific theories as separate units to be independently discovered or justified; instead they are considered as "large-scale, relatively long-lived conceptual structures", e.g. Kuhn's paradigm and Lakatos's research program (Laudan *et al.*, 1986). In addition to pure scientific factors, Kuhn (1970) and Feyerabend (1975) argued that metaphysical, psychological, sociological, and other nonscientific factors play an important role in the development and judgment of conceptual structures or theories. Scientific activities are conducted under the conceptual structures or theories that scientists hold. The main task of scientists is to elaborate and maintain the theories they hold (Kuhn, 1970).

Theories, once accepted, are rarely if ever abandoned simply because of empirical difficulties (Kuhn, 1970; Lakatos, 1978). Thus, empirical evidence is less important in the judgment of theories than was previously thought. Observations and experiments do not provide sufficient grounds for making unambiguous choices between competing theories since there are not objective, neutral observations in science; observations are theory-laden. Empirical evidence becomes raw data for scientists' interpretation based on the theories they hold. While Lakatos (1978) argued that a crucial experiment may serve to decisively falsify a theory, Pinch (1985) replied that a crucial experiment is testing the theorists involved rather than the theory itself, based on his own historical case study of solar neutrinos. He suggested that the theory test is a matter more of social convention rather than logic.

Therefore, a theory, always confronted with apparent empirical difficulties, is never rejected unless there is a new theory available to replace it. Kuhn (1970) asserted that competition among paradigms is the exception rather than the rule while Laudan (1977) claimed that it is the rule rather than the exception. However, after a theory change, the new theory seldom accommodates all the explanatory successes of its predecessor and frequently leads to a reinterpretation of the evidence previously thought to support its predecessors (Feyerabend, 1981). Thus, scientific knowledge is not cumulative after the revolutionary science stage, but only in the normal science stage (Kuhn, 1970).

Besides the philosophers of science, sociologists

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of science have joined to reveal the nature of science through empirical studies (e.g., Latour & Woolgar, 1986; Pinch, 1986). Traditional characteristics of science in the sociology of science were proposed by Merton as early as 1973. These are the so-called Mertonian norms, composed of universalism, communism, disinterestedness, and organized skepticism, which guided early sociology of science. The Mertonian tradition has been called the sociology of error, in which sociological research focused on erroneous knowledge and the social factors involved, with a peaceful labor division with philosophers of science, whose major concern is the truth of knowledge (Woolgar, 1988).

The distinction is no longer accepted by sociologists of science, who have sought to extend sociological analysis beyond the study of social factors external to science into the internal realm of what social processes are involved in the construction, assessment, and evaluation of scientific knowledge. Recently, this new approach has uncovered empirical evidence counter to the Mertonian norms and demonstrated the value-laden and human nature of scientific enterprise (Hull, 1988; Pinch, 1986). The generation and justification of scientific knowledge appears not to follow the pure or rational way proposed by the Received View; rather it is " socially constituted enterprise shaped at many levels by human values, beliefs and commitments" (Kelly *et al.*, 1993).

2. Students' Understanding of the Nature of Science

Earlier research on high school students' understanding of the nature of science consistently found that students held that scientific knowledge was absolute and that scientists' primary objective was to reveal natural laws and truths (e.g. Wilson, 1954; Mead & Metraux, 1957). Wilson employed his self-made quantitative instrument to measure the understanding of the nature of science of 43 high school students while Mead and Metraux collected 3500 high school students response to the question "What Do You Think About Science and Scientists?" and conducted a qualitative analysis.

Klopfer and Cooley (1963) developed the Test on Understanding Science (TOUS) which has become a popular paper-and-pencil instrument for measuring students' understanding of the nature of science. They concluded that students' understanding was inadequate. Later, Miller (1963), Mackay (1971), and Aikenhead (1973), using TOUS, reported the same findings. In addition, Rubba developed the Nature of Scientific Knowledge Scale (NSKS) and found that 30% of the high school students in their study believed that scientific research aimed to uncover incontrovertible and necessary absolute truth. Most of the students in Rubbaës study maintained that scientific theories developed through constant testing and confirmation, and then become laws (Rubba & Andersen, 1978).

Not all research has produced a result that students' understanding of the nature of science was inadequate. Lederman (1986) used NSKS to investigate 18 senior high school biology teachers and their students. He found the students scored higher than the "neutral" position on each NSKS scale except for the Parsimonious subscale, and that the teachers scored higher than the "neutral" position on each NSKS scale. He argued that they possessed the desired conception of the nature of science and must be considered to have adequate understanding of the nature of science. From his viewpoint, the arithmetic proximity of teachers and students' understanding is not of primary concern. In latter research, Lederman and O'Malley (1990) combined both paper and pencil questionnaires and follow-up interviews to investigate the tentative nature of scientific knowledge held by high school students. They found the students used "prove" as an expression for experimental support without any absolute sense, and that the students did not mean to imply that scientific laws were proven in any absolute sense, rather as a type of scientific knowledge which had more experimental support than theories. They also found many high school students never thought about issues regarding the nature of science and suggested that science teachers regularly ask their students to take "time out" to "step back" and analyze the knowledge which they have been asked to learn. They argued that such classroom discussions may prove to be invaluable for the development of students' understanding of the nature of scientific knowledge.

Aikenhead and his colleague (Aikenhead, 1987; Fleming, 1987; Aikenhead, Fleming, & Ryan, 1987; Ryan, 1987; Aikenhead & Ryan, 1992) conducted a six-year research to monitor student belief about STS topics using a large sample of graduating high school students. This study developed a multiple choice instrument, Views on Science-Technology-Society (VOSTS), whose choices for each statement were empirically derived from students' writing and from a sequence of interviews. VOSTS with three domains, the external sociology of science, the internal sociology of science, and epistemology, contains a wide range of issues regarding the nature of science. They found that almost all the students held that scientific knowledge is tentative but had three main views, a reconstructionist view (about 45%), a cumulative view (about 20%), and an exclusively technological view (about 20%). They also found that the phrase "the scientific method" meant many different things to different students, but found a consistent vague conception of "meticulously and rigidly following prescribed laboratory procedures." Most students, they reported, held an authentic view of science, in which science is subject to internal and external social influences, but about 20% of the students saw science as being isolated from such social influences.

II. Method

Senior high school students' understanding of the nature of science was documented by two kinds of data. One is notes of interviews that were carried out during the course of the development of UNOS, and the other is analysis of the students' responses to UNOS. A previous version of UNOS, containing 78 statements, was developed after a detailed review of the often-used instruments and recent developments in the philosophy , history, and sociology of science. Ten experts and three senior high school science teachers were asked to review and criticize UNOS.. Also, fifteen senior high school students were interviewed to make sure the phrases and meaning of the statements in the UNOS understandable to them. During the interview, each student was asked to go through every item of statement, to see if he could understand it and to get his opinion on every item. In the interviews, the students' ideas concerning the nature of science were recorded by pencil and paper.

1. Samples

The target population of this study was senior high school students in the Taipei area, and stratified random sampling and cluster sampling were employed. First, according to the minimum score for the Public Senior High School Entrance Examination and the schools' social reputation, all the public senior high schools in Taipei area were divided into three groups; then, in each group, one school was selected. In every selected school, a number of classes were randomly selected. All the students in every selected class were counted as research subjects. A total of 42 classes, ranging from grade 10 to grade 12, were selected from three senior high schools. After deleting useless data, there were 1670 samples in the study.

Owing to the limited target population of the public senior high school students in the Taipei area, the implication of this research should be considered cautiously. Suggestions are made as follows:

A. Although there are differences among the various areas and schools in Taiwan, all the senior high school students have two common backgrounds. They have the same curricula in junior high schools and have passed the Public Senior High School Entrance Examination. They also have the same aim in their current education: they are working hard for a college level education. Therefore, they are homogeneous to a very high degree. Research conclusions presented here can be applied to the other areas with caution.

B. Schools in other tracks, like vocational schools, have remarkably different roles and aims. This heterogeneity can not be neglected. Therefore, the author suggests that research conclusions presented here should not be applied to students in other tracks

2. Instrument

The development and validation of the Understanding of the Nature of Science Scale, UNOS, was documented in a previous article, (Lin, 1996). The reliability of UNOS and its three subscales, Nature of Scientific Method, NSM, Nature of Scientific Knowledge, NSK, and Nature of Scientific Enterprise NSE, was reported in Cronbach (.90, .74, .79, .77, respectively. The validity of UNOS was reported concerning its significant correlation with an often-used instrument, the Scientific Processes Inventory, SPI. UNOS is a four-point Likert scale, composed of three subscales. The three subscales are designed to measure the understanding the nature of the scientific method, the nature of scientific knowledge, and the nature of scientific enterprise, respectively. Each subscale contains 24 statements arranged into three topics. Half of the statements are phrased negatively, half positively. A particular understanding of the nature of science within subscales is measured by a pair of statements with one negative statement and one positive statement. The scheme of UNOS is summarized in Table 1.

3. Data Analysis

Respondents were asked to respond to statements with four options, Strongly Agree (SA), Agree (A), Disagree (D), and Strongly Disagree (SD). For positive statements, responses with SA, A, D, SD were scored 4, 3, 2, 1, respectively, while for negative statements, response with SA, A, D, SD scored 1, 2, 3, 4, respectively. The direction of each statement was

Table 1. Scheme of the "Understanding of the Nature of Science Scale, UNOS"

Subscale I : The Nature of the Scientific Method, NSM
Topic 1: The uniqueness and application of the scientific method
Topic 2: The objectivity of the Scientific Method
Topic 3: The Rationality of the Scientific Method
Subscale II: The Nature of Scientific Knowledge, NSK
Topic 4: The Various kinds and Roles of Scientific Knowledge
Topic 5: The Ontological Status of Scientific Knowledge
Topic 6: The Epistemological Status of Scientific Knowledge
Subscale III: The Nature of Scientific Enterprise, NSE
Topic 7: The Assumptions, Definitions, and Aims of Science
Topic 8: Scientists and the Scientific Community
Topic 9: Science and Society

predetermined based on the literature review described at the beginning of this paper and other research in the fields of science education and social studies of science. Statistical analyses were performed using the PC SPSS Package.

III. Results and Discussion

The main purpose of this study was to investigate the understanding of the nature of science among high school students sampled in the Taipei area. The average score for the whole scale of UNOS was 217.73, and the average scores for the three subscales were 72.29, 72.85, and 72.60, respectively. The possible highest score is 288 for the whole scale and 96 for each subscale; the mid-score is 180 for the whole scale and 60 for each subscale. It was suggested those whose scores, measured by a Likert scale concerning their understanding of the nature of science, were higher than the scale's mid-score should be regarded as having an adequate understanding of the nature of science (Lederman, 1986). Thus, this study revealed that the high school students understood the nature of science to an acceptable degree. However, the average scores do not tell very much; there is a need for systematic analyses in order to further understand the students' understanding of the nature of science. Further analyses were done on the interview data and responses to the statements in UNOS, and are reported in the following sections.

1. Analyses on Interview Data

Although the students sampled are shown to have an adequate overall understanding of the nature of science, it is worthwhile document interview data, acquired during the period of development of the instrument, in order to further comprehend high school students' understanding of the nature of science. The interview data were derived from notes of interviews with fifteen high school students. Though they were not among the 1670 students studied, a number of viewpoints they held concerning the nature of science deserve to be reported to help us grasp high students' image of science. The interview data reported in the following sections were not the consensus of all the fifteen students, but the opinions of the most of them. These opinions are also of philosophical interest.

It has long been held by many scientists and mathematicians that good science can be stated in the form of mathematical formulas and that such representations push science to the summit of knowledge. Therefore, physical science, which is easier to represent using mathematics, is thought of as better science than biological science, which is hard to represent using mathematics. High school students interviewed possessed the same notion and gave remarks like "physics is science; biology seems to be a kind of history" and "biology is science in definition, but it requires memorization of lots of stuff, so it could be a matter in the middle position between physical science and social science." Such responses showed that those students tended to confine science to the very scope of physical science.

Since the beginning of the current century, the development of the philosophy of science, almost exclusively, has attracted many physicists and mathematicians into the field. They have been inclined to look for metaphysical concepts in physical science and to examine the properties and relations among them. Moreover, the conclusions derived from physical science have been thought to be applicable to the various fields of science or knowledge. An obvious instance is that they classify scientific knowledge into two groups, laws and theories. A law of nature is a generalization of a given nature phenomena; a theory is a knowledge structure used to explain a natural law. Students in our interviews were quite familiar with the terminology but could not understand their original definitions. They commented "a law can be thought of as a theory, but a theory can not be thought of as a law." Nor did they see the inherent difference between a law and a theory. They expressed a mistaken view that "the difference between a law and a theory is a matter of time and experimentation." The epistemological status of laws and theories was also confused. They declared that "scientific knowledge is not the absolute truth" though, "by continuous discoveries and accumulation of positive evidences, hypotheses or theories can become truth (law)."

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There are two points which need to be noted. First, students in this study accepted that scientific knowledge can be classified into laws and theories. The division was initially presented by logical positivists based on their research on , mainly, physical science. In fact, this classification is not appropriate for all sciences. In biological science, knowledge is seldom presented by means of laws, but often by means of concepts (Mayr, 1982). Secondly, the original distinction between laws and theories was overlooked. In logical positivism, they are different in kind, not in degree. However, the students in this study maintained that scientific enterprise moves scientific knowledge from being less certain, theories, toward being more certain, laws. Theories and laws are different in degree in the minds of these students.

Also, they mixed the traditional and new philosophy of science together. When they took science to be fallible, as proposed by the new philosophy of science, they meant theories. When they took it to be truth or approximate truth, as proposed by the traditional philosophy of science, they meant laws. This mixture was a reasonable way to satisfy both the traditional and new philosophies of science simultaneously. However, it was obvious that they had difficulty appreciating the local and statistical property of laws, as Cartwright suggested (1983).

Science textbooks, such as biology textbooks used in junior and senior high schools in Taiwan, often present the scientific method as a strict way of observing phenomena, posing a question, forming a hypothesis, testing it by means of experiments, proposing a theory, and refining the theory into a law. However, the students in this study considered "it not necessarily so." Moreover, for them, the scientific method is " a habit or attitude that normal people use to deal with everything." It is not exclusively employed in the field of science. Besides, they did not consider that there is a direct connection between empirical data and scientific theory, where many a "tip" must be involved. Empirical science alone can not entail scientific theory, and often, they said, "wrong scientific knowledge even is derived from the results of experiments or observations." The responses noted above reflect their disagreement with the over-simplified scientific method normally taught in science textbooks. This indicated that these high school students know the meaning of the scientific method better than those who write science textbooks. Unfortunately, science teachers often place more emphasis on the content of the subject matter and leave students' understanding of the nature of science or scientific method to chance. This will severely hinder the development in students of the understanding of the nature of science. Moreover, it is worth noting that most science teachers accept positivist philosophies of science, which represent a distorted image of science (Hsu, 1992). To improve students' understanding of the nature of science, there is a strong argument for inclusion of the nature of science in the science curricular and science teachers' preparation programs (Summers, 1982; Department of Education and Science and the Welsh Office, 1989; King, 1991; AAAS, 1993; NRC, 1996).

Traditionally, scientific enterprise has been regarded as existing in the "ivory tower". The interview notes revealed that the high school students did not hold this notion; they noted that scientists can be influenced by personal interests and the social environment. However, they insisted that scientists should pursue a life of "pursuing the truth", "sacrifice and dedication", "purification without considering outside influence" to a certain degree. This positive impression was evident in their opinions on budgetary allocations. They recommended the science budget should be ranked as the top priority because, as one of them proposed, science is "hope for the future". The positive attitude toward science is an important goal of science education and could be a drive which may lead students to taking science courses or career.

2. Analyses of Responses to the Statements

The analyses of 1670 students' responses presented in this section included four aspects. First of all, a comparision of the reponses between positive and negative statements was made, in which it was revealed that of the most students still believed the myth regarding scientific method and knowledge. Next, analyses were done on the three subscales to further reveal the students' understanding of the nature of science.

A. A Comparison of The Responses Between Positive and Negative Statements

The pattern of these high school students' responses to the statements might show their attitudes toward science and their understanding of the nature of science. As noted above, the statements were constructed in pairs. One was phrased positively, and the other one was negatively. Theoretically, respondents should get equal scores for the two opposite statements in a pair. However, a comparison of the scores between positive and negative statements revealed that total scores for the positive statements were signifi-

Table 2. A comparison of scores for positive and negative statements

Scale	statement	MEAN	SD	Df	t-value	P
UNOS	Positive	112.10	11.93	1669	19.77	.000**
	Negative	105.63	12.84			
NSM	Positive	37.34	4.43	1669	18.13	.000**w
	Negative	34.95	4.64			
NSK	Positive	38.43	4.83	1669	30.09	.000**
	Negative	34.43	4.84			
NSE	Positive	36.34	4.25	1669	.65	.515
	Negative	36.26	5.20			

Table 3. The responses to statements 51 and 17

51. The methods dealing with other than scientific problems are as important as the methods used in natural science. (+)

17. Compared with the various methods used to solve other kinds of problem, the method used in natural science is better. (–)

Statement No.	17			
	Response	SA & A	D & SD	Row Total
51	D & SD	84	88	172/10.4%
	SA & A	706	781	1487/89.6%
	Column Total	790/47.6%	869/52.4%	1659/100%

cantly higher than those for the negative statements in UNOS and subscales NSM and NSK (Table 2). Only the scores for the subscale NSE were almost the same for the two sorts of statements. Table 3 shows the inconsistent responses. For the statement pair 51 and 17, statement 51, a positive one, got 1487/89.6% of the responses with "Strongly agree" and "disagree" while statement 17, a negative one, got only 790/47.6% of the responses with "Strongly disagree" and "disagree" (Table 3). For statement 51, almost 90% (1487) of the high school students in the study agreed that all kind of methods are equally important, no matter whether they are scientific or not while for the negative statement 17, more than half of the 1487 students (781) turned to agree that the scientific method is the best, compared with other methods. The 781 students were accordingly supposed to disagree statement 17, since they agreed the statement 51, which is opposite to statement 17. Their inconsistency in responses to negative and positive statements may reduced their scores in the negative statements. The significant difference in scores between positive and negative statements occurred in subscales NSM and NSK, not in subscale NSE, indicating that students held a more appropriate image of the nature of scientific enterprise than of the nature of scientific method and knowledge.

Table 4. The responses distribution of statements 5, 52 and 17

5. The research methods in science are unique and much different from those in other disciplines. (–)

17. Compared with the various methods used to solve other kinds of problem, the method used in natural science is better. (–)

17. Applying the scientific method, step by step, to a problem will always lead to the correct answer. (–)

Statement No.	SA	A	D	SD
5	165/9.9%	438/26.2%	750/44.9%	305/18.3%
17	117/7.0%	675/40.0%	715/42.8%	156/9.3%
52	97/5.8%	436/26.1%	851/51.0%	279/16.8%

Table 5. The response distrubiton of statements 71 and 10

71. A scientific report is made from research results that a scientist considers worth reporting. (+)

10. A scientific observation report is an exact, uninterpreted document on the experimentation procedures. (–)

Statement No.	SA	A	D	SD
71	344/20.6%	865/51.8%	336/20.1%	117/7.0%
10	173.10.4%	407/24.4%	616/36.9%	447/26.8%

B. The Understanding of The Nature of Scientific Method

Statements shown in the Table 4 were concerned with the status and application of the scientific method. More than one-third of the students strongly agreed or agreed that the scientific method is unique and much different from methods used in the other disciplines as given in statement 5. Moreover, for statement 17, almost 50% of the students strongly agreed or agreed that the scientific method is the best method among the various methods. Not only did the students put the scientific method in a unique and majestic position, but some students also were convinced of the power of the scientific method in acquiring knowledge. For statement 17, over 30% of the students strongly agreed or agreed that "applying the scientific method, step by step, to a problem will always produce the correct answer."

Statements 71 and 10 were concerned with the nature of observation and reporting. For statement 71, around 30% of the students disagreed or strongly disagreed with the statement that the content of scientific reports is screened in accordance with scientists' favorite interests or theories (Table 5). Likewise, for statement 10, more than 30% of the students agreed or strongly agreed that a scientific report is nothing but "an exact, uninterpreted document on the procedures of experimentation" (Table 5). The objectivity

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Table 6. The response distrubiton of statements 42 and 13
42. The meaning of experiment results is determined by the scientific theory used. (+)
13. The interpretation of experiment results is rigid and will not vary from one to other. (–)

Statement No.	SA	A	D	SD
42	268/16.0%	944/56.5%	370/22.2%	84/5.0%
13	168/10.2%	300/18.0%	666/39.9%	528/31.6%

Table 7. The response distrubiton of statement 65.
65. Scientific knowledge can prescribe the occurrence of a particular event. (–)

Statement No.	SA	A	D	SD
65	191/11.4%	761/45.6%	487/29.3%	216/12.9%

Table 8. The response distrubiton of statements 34, 47, and 30
34. Scientific models (e.g., atom) are exact duplications of the objects involved. (–)
30. Based on scientific observation, scientific models (e.g., atom) are proposed to be copies of reality. (–)

Statement No.	SA	A	D	SD
34	133/8.0%	552/33.1%	652/39.0%	327/19.6%
30	263/15.7%	730/43.7%	449/26.9%	219/13.1%

Table 9. The response distrubiton of statements 22 and 37
22. As long as experiments and observation are well done, it is possible to produce a scientific theory. (–)
37. Statements are not accepted as scientific knowledge unless they are absolutely true. (–)

Statement No.	SA	A	D	SD
22	292/17.5%	694/41.5%	510/30.5%	167/10.0%
37	240/14.4%	552/33.1%	689/41.3%	178/10.7%

of observation was once thought as the fundamental basis for the scientific method, but it has been evidently demonstrated by many philosophers of science that observation is theory-laden. It seems that these students overlooked the newer findings regarding the nature of observation.

The statements shown in the Table 6 were designed to investigate the students understanding of the relationship between empirical data and scientific theories. Around 30% of the students insisted that the interpretation of empirical data has no connection with the theories used or the interpretation will not vary from one scientist to another. This is a traditional view held by positivists. Chang (1995) carried out a study on Taiwanese graduate students' beliefs about scientific knowledge and reported similar findings. In his study, more than half of the graduate students strongly disagreed or disagreed with the statements "Theories guide observations" and "Theories limit observations". Chang suggested the students held positivist views of the relationships between theories and observations.

C. The Understanding of The Nature of Scientific Knowledge

It is very sad to note that more than half of the students believed that scientific knowledge had the function of prescription (Table 7). This notion presumably came from the philosophy of science based on the classical physical science with a closed system. Cartwright (1983) argued that the deepest and most admired successes of modern physics do not in fact describe regularities that exist in nature. The concept of prescription is difficult to apply in the field of quantum mechanics, which is thought to have the probability property regarding the nature world. Neither can be applied in the field of life science, in which variables are not confined within a closed system. At best, prescription is just a property for particular sciences, not universal for all kind of sciences.

The responses to the statements in Table 8 showed that more than 40% of the students believed in the ontological reality of scientific knowledge. The debate between the Copenhagen Interpretation and Einstein revealed a new way of viewing the world. The Copenhagen Interpretation does not care what scientific knowledge is about and gets away from the idea of one-to-one correspondence between reality and theory. The important thing is if scientific knowledge works in all possible situation. It is the pragmatic property of science that almost half of the students can not appreciate.

Two common epistemological myths about science are the notions that empirical data direct scientific theories and that scientific theories are absolutely true. About half of the students in the study accepted these two notions (Table 9). The former notion comes from the empiricist tradition and regards sense experience as the most fundamental ground for knowledge. Moreover, this tradition very much neglects the role of human imagination in the development of scientific theories. However, the new philosophy of science has demonstrated that the relationship between theories and empirical data is much more complex than this rigid image of science. The latter notion reflects the tradition Lakatos called verificationism, in which

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scientific knowledge gets its truth value through the use of induction in the processes of verification or confirmation. However, the problem of induction have not been solved since the time of Hume. This brings the alleged truth value of scientific knowledge into question. Popper suggests that scientific knowledge is fallible. A more appropriate image of science with room for imagination and flexibility seems to be foreign to these students.

(4) The Understanding of The Nature of Scientifice Enterprise

The subscale NSE aimed to investigate the students' understanding of the nature of scientific enterprise. Its main concern is directed to the understanding of scientists and the scientific community, and the relationship between science and society. Among 24 statements in this subscale, there were as few as four statements where more than one-third of the students' responses conflicted with the initial expectation, which indicated that most of the students have a rather adequate understanding of issues regarding the nature of scientific enterprise. Also, this result confirmed previous findings described in the preceding section.

The two statements in Table 10 dealt with the students' image of scientists. More than half of the students accepted that scientists are more objective than others. Perhaps because of this perception, almost 60% of the students admitted a special respect for scientists' opinions on social issues, even those outside their expertise. This impression might go back hundreds year ago, when science was not as popular as it is today and when most scientists belonged to the upper classes. Moreover, it perhaps has been reinforced by some distinguished scientists, like Einstein or Watson, in recent decades. These famous scientists no doubt were among the elite in the world, but there is not necessarily any connection between elite status and objectivity. Also, if objectivity is related to elite status, it should not exclusively belong to scientists. It should belong to the elite in all fields. The students' image of scientists apparently is a myth. Besides, the tremendous change in science careers is worth noting. Since the turn of this century, especially since the World War II, science has become institutionalized. If the term scientist means a person with a career in science, then scientists can be divided into various levels, from top to bottom, senior to junior. It is obvious that most people with the title of scientist are unknown to the public and that they are not necessarily elite as well as objective. The recent change of the property and status of scientists seems unaware

Table 10. The response distrubiton of statements 33 and 66
33. Generally, scientists are more objective than others. (–)
66. Due to their professional training, scientists' opinions on any social issue should be highly valued. (–)

Statement No.	SA	A	D	SD
33	163/9.8%	717/42.9%	622/37.2%	161/9.6%
66	211/12.6%	759/45.4%	525/31.4%	164/9.8%

Table 11. The response distrubiton of statements 69 and 36
69. Scientific research is so independent that the way of selecting methods will not be affected by the scientific community.(–)
36. Most scientists will not generally do research which goes against their religious and ethic views. (+)

Statement No.	SA	A	D	SD
69	147/8.8%	393/23.5%	816/48.9%	306/18.3%
36	215/12.9%	666/39.9%	559/33.5%	226/13.5%

for the most students in study.

One other question worth noting is whether scientists are rational and always free from external or internal influence. Table 11 shows that more than one third of the students agreed or strongly agreed that scientific methods are not affected by the scientific community. However, Kuhn suggests that this paradigm serves as the way of seeing and that the scientific community is the top authority to determine science. In reality, the work of modern institutionalized scientists is often mission oriented, where scientists bear pressure related to funding and publication. In this sense, scientists and scientific work are much guided by the scientific community and paradigm with less freedom of research and individualization than usually thought. It seems that these students are not well informed of the nature of scientists and scientific enterprise. Likewise, for statement 36 in Table 11, almost half of the students disagreed or strongly disagreed that scientists will not conduct research which conflicts with their value systems. The history of science demonstrate that this is not the case. Sticking to a deterministic view of the world, Einstein was shocked by the concept of quantum indeterminism and dismissed it with the response that "God does not play dice with the universe!" He spent much of the rest of his life for searching the deterministic clockwork that he thought must lie hidden beneath the apparently random world of quantum mechanics. Until his death, Einstein never accepted the indeterministic view of the world. This piece of history shows that scientific work is often driven by personal value systems.

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IV. Conclusion

The students in this study had an adequate understanding of the nature of science, with average scores higher than the scales' mid-score. Further analyses, however, showed that they believe more myths regarding the scientific method and knowledge than they do regarding scientific enterprise.

Analyses on interview data, derived from notes of interviews with fifteen high school students, revealed that the students' definition of science was closer to that of physical science than to that of biological science. For them, physical science is more scientific than biological science. Also, it seemed that they had difficulty appreciating the difference in kind between scientific theories and laws. Moreover, interview data showed that they did not agree with the over-simplified version of the scientific method often conveyed in science textbooks. Furthmore, they understood that science is not a kind of ivory tower any more though they insisted that scientists should lead an ideal life with, more or less, pure internal motivation and without external influence.

Analyses of the 1670 students' responses to the statements also revealed significant issues. More than 30% of the students showed high respect for the scientific method and believed that the scientific method, if followed step by step, will lead to the correct answer. Around 30% of the students held that scientific observations and reports were nothing but exact and uninterpreted documents of phenomena. About 30% of the students insisted that empirical data have inherent meaning, unaffected by the scientific theories or scientists involved.

As to the nature of scientific knowledge, more than half of the students had difficulty appreciating the property of being local for scientific knowledge. Also, more than 40% of the students accepted the ontological reality of scientific knowledge. Moreover, about half of the students in this study accepted two common epistemological myths about science, which are the notions that empirical data directs scientific theories and that scientific theories are absolutely true.

For 24 statements regarding the nature of scientific enterprise, there were as few as four statements where more than one-third of the students' responses conflict with the initial expectation. Similar to the students interviewed, almost 60% of the students showed special respect for scientists and their opinions, even those on issues outside their expertise. Likewise, more than one third of the students agreed or strongly agreed that scientific methods will not be affected by the scientific community, and almost half of the students disagreed or strongly disagreed that scientists will not conduct research which conflicts with their value systems. The students had better understanding of the nature of scientific enterprise though it seems that they were not well informed about the nature of modern scientists.

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高中學生對科學本質的了解

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摘　要

了解科學本質已經成爲科學素養的一個重要元素及科學教育的重要學習結果。本文基於對高中學生的面談資料與施測「了解科學本質量表」的結果，目的在於報告高中學生對科學本質的了解。面談學生爲 15 人，施測學生爲 1670 人。施測結果分析，全體學生對「了解科學本質量表」的平均分數高於量表的中數，因此認爲學生對科學本質具有足夠的了解。另在分量表上，學生在科學方法與知識上有較多的迷思。分析面談資料發現學生對科學的定義較近於物質科學，而較遠於生命科學，而且學生未能理解科學理論與定律間的不同。學生通敍無法同意教科書上所描述的過於簡化的科學方法。此外，認爲科學 家多少仍過著單純的生活，不受外在的影響。分析施測的結果，對科學方法的本質，學生表示對科學方法的高度尊敬而且認爲經驗證據本身有其內在意義，部份學生認爲科學觀察與報告是未經詮釋的。對科學知識的本質，部份學生仍對科學的普適性、本體實體、與絕對真理有迷思。在科學事業的本質方面，大部份學生仍無法充分理解現代科學家的本質。

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Cultivating Capabilities of Teachers in Promoting Student Creativity: Designing STS Exploratory Experiment

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Abstract

This study aimed to cultivate the capabilities of teachers in developing student creativity by designing STS exploratory experiments. A dynamic curriculum framework was designed including a five-phase learning procedure with 22 processes associated with creativity. The 22 processes included learning as well as assessment tasks used in: (a) finding evidence of creativity performance; and (b) evaluating the effectiveness of teacher development. A three-stage teacher development program was also designed as a dynamic guideline for planning learning activities. Action research was conducted with a curriculum experimental trial to develop creativity and evaluate the effectiveness of the framework and stage 1 of the teacher development program. Video-based anchors were designed and used for small group and class cooperative learning about basic thinking skills: brainstorming, role playing, debating, and mapping. Each group identified an STS topic, designed an exploratory experiment with scaffolding strategies, and presented it to the class for challenge and criticism. The lead group defended, debated, and revised the material. Then, each group took turns leading class activities. The results were displayed as posters, which were evaluated by the class. The whole process was videotaped. Data from direct observation, video-taped records, portfolios, and peer assessments were analyzed. The results were as follows. (1) Fluency measurement showed (a) Fluency in divergent thinking of individuals was in a normal range. (b) Small group and class learning promoted divergent thinking. (2) Flexibility in thinking was analyzed in terms of four dimensions: experience based, analogical, analytical, abstract. For all the groups, experience based thinking (that related to life and chemistry experiments) was used predominately, reflecting the academic background of the participants, followed by the other dimensions in decreasing order. (3) The design of the case group was evaluated for (a) originality, (b) tangibility, (c) scientific thinking, (d) scientific skills, (e) dramatic value, and (f) acceptability. The class ruled that the design met all criteria but (f). The experiences and products substantially improved creativity and professional capabilities of the preservice teachers in developing learners' creativity.

Key Words: Creativity, performance-based assessment, STS exploratory experiment, teacher development

I. Introduction

In traditional science teaching, learners could transfer only little of their learning to real life situations (cf. Wheatley, 1991). Experience in a real situation is the fundamental way to develop science literate citizens possessing the capabilities of creativity, higher order thinking, value analysis, and ethical and moral consideration. In STS learning, learners not only learn the needed elements , but also make combined use of these learning elements to solve newly encountered real life problems (Rubba, 1991).

The tenets of STS (Yager, 1990) include components of creativity similar to those described by Torrance (1966), e.g., questioning, elaboration of possible causes of a particular situation, and possible consequences of certain actions. Science teaching using issue-oriented strategies can significantly improve certain creativity skills of grade 7-9 students. The number of questions, possible causes, and possible consequences were found to be twice as much for STS students as for students in classes using standard textbooks (Penick & Yager, 1993). Teachers are the key to success in science education reform. To implement programs related to creativity, teachers must be aware of the importance of creative effort - in learning, in the profession, in scientific pursuits, and in personal living (Parnes, 1991). Teachers must also have professional capabilities (Wang, 1995a) which they can use to develop student creativity. No program, however, has been reported which trains STS teachers in this way. The purpose of this study was to cultivate the capabilities of teachers in developing student creativity through the design of STS exploratory experiment.

II. Research Design

1. Rationale

This study was based on the following rationale: (1) Curriculum development using the RDDA (research, development, diffusion, and adoption) model has been found to be ineffective in several cases. The division of labor between goal setters and goal implementers, and between practitioners and evaluators should be eradicated (Yager, 1992; Wang, 1994b). (2) Teachers should be personally involved in designing teacher development programs (Wang, 1997). (3) Teachers should be personally involved in developing ways to solve STS problems (Shulman, 1987; Wang, 1994a,b). (4) Teachers should learn how to learn, teach, and construct knowledge (Cunningham, 1991). Instruction must move the novice toward independence for future professional practice. This can be accomplished through anchored and scaffolded instruction or regulation of task difficulty, thus gradually reducing the instructor's support as the learner's proficiency increases (Bruner, 1978; Pearson & Fielding, 1991; Rosenshine & Meister, 1992; Wang, 1995b). (5) It is possible to design educational programs to develop creativity (Parnes, 1981) and relevant capabilities of teachers.

2. Linking Instruction and Assessment

A dynamic curriculum framework was designed, which included a five-phase dynamic learning procedure with 22 processes (P1.1-P5.6) (Table 1) (Treffinger, 1986); these were also assessment tasks. A three-stage teacher development program was designed as a guideline for planning learning activities to cultivate the capabilities of teachers and develop student creativity (Feldhusen & Goh, 1995; Treffinger, 1986; Caropreso & Couch, 1996; Wang, 1994b, 1995b, 1996, 1997a,b). The assessment tasks were used to: (a) find evidence of performance indications for creativity; and (b) evaluate the effectiveness of the teacher development program. Action research was conducted to develop and evaluate the framework and the program. To make these designs effective and useful for learners/teachers, the following actions were accomplished: (1) sample cases were produced showing how to conduct activities; (2) clear descriptions of assessment tasks were prepared; and (3) sample evidence for (a) performance indications of creativity and (b) teachers' capabilities were collected.

Table 1. Five-phase procedure for developing creativity and teachers' capabilities through the design of STS exploratory experiments

(P1) Be aware of an issue: Problem-finding.
- (P1.1) Be aware of an issue and its problems.
- (P1.2) Identify a problem to be investigated.

(P2) Understand the problem.
- (P2.1) Find facts: Observe, search, analyze, and organize.
- (P2.2) See the problem from different viewpoints and redefine it.
- (P2.3) Experiment with materials and devise tests to obtain explanations.
- (P2.4) Organize information for understanding.

(P3) Propose solutions with explanations.
- (P3.1) Find ideas: Use open-ended, divergent thinking skills such as card brain storming and check lists, to discover new ideas; select one of the ideas.
- (P3.2) Find obstacles.
- (P3.3) Find solutions: Using thinking skills, such as flow charts and story methods, to develop unusual ideas into useful ones.
- (P3.4) Design procedures for an STS exploratory experiments as well as for teaching and scaffolding strategies.
- (P3.5) Evaluate the consequences of the proposed action plan, taking into account all relevant factors.
- (P3.6) Identify the rigorous, important standards or criteria the invention will meet.
- (P3.7) Present the plan for class evaluation; revise.

(P4) Execute the experiment.
- (P4.1) Conduct the experiment.
- (P4.2) Modify-Continually revise the process or product to completeness consistent with the criteria articulated earlier.
- (P4.3) Consider resources, cost, time, space and acceptability.

(P5) Evaluate - Display the results to evaluate for:
- (P5.1) originality, (P5.2) tangibility, (P5.3) scientific thinking, (P5.4) scientific skills, (P5.5) dramatic value, and (P5.6) acceptability.

3. A Curriculum Framework

The framework consists of the following components (Wang, 1994b, 1996a, 1997).

(1) Rationale and assumptions:

(a) Teachers build on students' experiences, assuming that teachers learn only from their own experiences.

(b) Creativity should include related creativity activities, such as thinking, sensing problems or the need to act, seeing the gap between knowledge and understanding, applying knowledge, imagining, judging the problem, and seeing opportunities to create new products or ways of making decisions and solving problems (Feldhusen & Goh, 1995).

(c) Everyone can be creative at some level; continued practice in using creative approaches should lead to increasing proficiency in creativity, regardless of whether the person is mentally retarded, average, or gifted.

(d) Creative problem solving (CPS) processes should be taught deliberately, both as general thinking skills in daily life and within subject matters (Parnes, 1991).

(2) Goals and objectives:

Goals:

(a) To develop creativity and attitude necessary for problem sensing, problem understanding, idea finding, and problem solving;

(b) to construct relevant professional capabilities of teachers; by planning and conducting STS exploratory experiments.

Major objectives:

(a) Focusing on future trends, identifying needs of human adaptation and alternative futures.

(b) Dealing with life related problems and societal issues as goals which produce a need for creative thinking.

(c) Problem solving and decision making using scientific knowledge in social contexts.

(d) Career awareness as an integral part of learning.

(e) Integration by students of creative problem solving strategies into their lives while considering practical, value, ethical, and moral dimensions of problems and issues.

(f) Improved abilities associated with creativity, enabling students to:

(i) sense problems, challenges, and opportunities;

(ii) observe, discover, and analyze relevant facts;

(iii) see problems from different viewpoints and redefine them productively;

(iv) defer judgment and break away from habit-bound thinking;

(v) discover new relationships;

(vi) use check lists to discover new ideas;

(vii) refine unusual ideas into useful ones;

(viii) evaluate the consequences of proposed actions while taking into account all relevant criteria; develop and present ideas for maximum acceptability;

(ix) develop action plans and implement ideas and solutions; and

(X) check the effectiveness of actions and take corrective measures when advisable (Parnes, 1991).

(3) Characteristics of an STS exploratory experiment:

(a) Problem-centered, student-centered, flexible, and culturally as well as scientifically valid.

(b) Humankind central, individualized, and personalized.

(c) Multifaceted, including local and community relevance.

(d) Use of the natural environment, community resources, and the students themselves as foci of study.

(e) Information used by the students as persons in the context of a cultural/social environment.

(f) Portraying a more accurate view of the nature of science by explicitly making connections between science and society (externalism) as well as the isolated workings of science (internalism).

(g) Cooperative work on problems and issues.

(4) Classroom strategies:

(a) Using student thinking, experience, and interest to drive learning (meaning frequently altering teacher's plan).

(b) Using open-ended questions.

(c) Seeking out student ideas before presenting teacher 's ideas or before studying ideas from textbooks or other sources.

(d) Encouraging students to challenge each other's conceptualizations and ideas.

(e) Utilizing cooperative learning strategies which emphasize collaboration, respect individuality, and use division of labor tactics.

(f) Encouraging adequate time for reflection and analysis.

(g) Respecting and using all ideas that students generate.

(h) Encouraging use of thinking maps, self-analysis, collection of real evidence to support ideas, and reformulation of ideas in the light of new experiences and evidence.

(5) A five-stage procedure for developing creativity and capabilities of teachers through the design of STS exploratory experiments (Table 1).

Table 2. Selected Thinking Tools

1. Divergent	
(1) Open-ended thinking	
(a) Brainstorming	
(b) Card brainstorming	
(c) Brainwriting (635 method)	
(d) Mapping	
(2) Lateral	
(a) listing wants, needs, wishes, usages	
(b) Listing defects	
(c) Focus group interview	
(d) Check lists	
(e) Morphological analysis	
(f) Catalog method	
(3) Analogy	
(a) Synectics	
(b) NM method	
(c) Bionics	
(d) Mechanics	
2. Convergent	
(1) Library classification	(8) KJ method
(2) Cross method	(9) Categorical method
(3) Cause-Effect method	(10) PERT method
(4) Cause-Consequence analysis	(11) BD method
(5) Time-flow chart	(12) Story method
(6) Decision table	(13) Input-output method
(7) Attribute factor table	(14) ISM
3. Integral	
(1) High bridge method	(3) Experimental design
(2) Work design	
4. Attitude (affective)	
(1) Self-regulated thinking	(4) Zen
(2) Role playing	(5) Yoga
(3) Meditation	

(6) Tools for developing creativity, e.g., card brain storming, check lists, morphological analysis, synectics, role playing, and work design (Table 2).

(7) Assessment strategies.

Creativity is evaluated by analyzing the results of direct observation, video-taped records, portfolios (Coleman, 1994), and peer assessments. The creativity indicators (performance indicators) for judgment must be defined, communicated, and understood by affected parties. Fluency measurement is used to evaluate (a) the fluency of individuals; and (b) the effectiveness of thinking skills, small group learning, and class learning in promoting participants' divergent thinking. Flexibility is analyzed in terms of four dimensions of thinking: experience based, analogical, analytical, and abstract. The designs of creativity products are evaluated for (a) originality, (b) tangibility, (c) scientific thinking, (d) scientific skills, (e) dramatic value, and (f) acceptability. Professional capability includes the abilities to design and scaffold activities and to assess learning outcomes. The teacher's portfolio is assessed based on pieces of evidence relevant to a set of performance criteria (Wang & Hsieh, 1997b). The portfolio is developed in a value-added process. Using the portfolios, one can review a teacher's growth, achievements, ability to reflect on his/her work, and his/her ability to establish goals to meet the criteria. The portfolio includes: (a) a commentary on the real activity context for learning and teaching; (b) modules prepared by the teacher describing learning tasks, learning environment, analyses of teaching, anchoring, scaffolding, and learning across a series of activities as well as plans for each of the individual activities in the series; (c) assessments of learning outcomes, including a commentary; and (d) any additional information which the teacher believes represents his or her work as an STS teacher. Steps in the performance-based evaluation process are as follows: (a) teacher's self-evaluation developed in a portfolio format; (b) evaluator review teachers' portfolio; and (c) a portfolio conference.

4. A Constructivist Model to Develop Creativity and Capabilities of Teachers Through Designing STS Exploratory Experiments

The model consists of three stages, which moves a novice teacher to independence in professional practice through anchored and scaffolded instruction (cf. Treffinger, 1986; Wang, 1997a,b; Wang & Tsai, 1994b).

Stage 1. Learning basic thinking skills and designing STS exploratory experiment under anchored instruction.

Video-based anchors are designed and used as a macrocontext for situated learning. The information rich learning environment encourages learners to pose and solve complex, realistic problems related to the issue. Stage 1 attempts to help teachers learn thinking skills and experience the work of designing STS exploratory experiments from the learner's point of view. It is important that teachers have these experiences and learn how to provide guidance without being overly directive so as to meet constructivist principles.

Stage 2. Practicing thinking skills and designing STS exploratory experiments under scaffolded instruction

The curriculum framework is used by the teacher educator to scaffold and help novice science teachers work in small groups. They design STS modules, carry out the designed activities, evaluate their effectiveness in achieving the learning goals, and revise the modules. Instruction must move the novice teachers toward independence for future professional practice by reducing instructor support as learner proficiency increases.

Stage 3. Independent practice: dealing with real problems and challenges

Teachers should be given opportunities for independent practice in STS activities to promote learners creativity.

III. A Case

The case study, a portion of the action research, was designed to cultivate the capabilities of teachers in developing student creativity through the design of STS exploratory experiments as stage 1 of the teacher development program. (Case studies for stage 2 will be described elsewhere.) This study (1) collected evidence for (a) performance indications of creativity and (b) teacher capabilities; and (2) evaluated the effectiveness of the activities based on the design. The case study included here also shows how we proceeded with the activities.

1. Participants

The participants in the case study included the author (as a teacher, teacher educator, researcher, and facilitator) and 20 preservice teachers (hereafter called students; 13 males and 7 females) in the chemistry department of a teacher training university. The students were first timers in learning basic thinking skills (teacher development program, stage 1) and in designing STS exploratory experiments under anchored instruction.

2. Description of Activities

In this study, an activity-based, real life problem solving approach was used to promote creativity (Kitto, Lok, & Rudowicz, 1994). A five-phase model with 22 processes (P1.1 - P5.6) (Table 1) was used as a dynamic learning procedure along with assessment tasks to find evidence of performance indications for creativity and to evaluate the effectiveness of the activities.

The students were asked to think aloud as they attempted to solve a variety of problems in small group and class cooperative activities. They were advised to use mapping, check lists, card brain storming, flow charts etc. as thinking tools. Mapping was used to help learners: (1) link prior knowledge to new information; (2) understand relevant pieces of information and the relationship among them; (3) see the hierarchical, conceptual, and professional nature of knowledge (cf. Klausmeier, Ghatala, & Frayer, 1974); and (4) use valid and reliable tools to integrate and summarize a set of perceived units of reality to find problems for further explorations (Warfield, 1976; Wang & Hsieh, 1997a). It was emphasized that this stage was not a test of their problem solving capabilities, but was meant to evoke their creativity. They were given practice in thinking skills (Wang & Tsai, 1994a).

The author used video-based anchored contexts to promote the learners' open-ended thinking about the greenhouse STS issue. Small group and class cooperative learnings were used to learn basic thinking skills: brain storming, role playing, debating, and mapping. Each group identified an STS topic, designed an exploratory experiment with scaffolding strategies, and presented it to the class orally and in written form. The designed activities were challenged and criticized by the class. The lead group defended, debated, and revised accordingly. Then, each group took turns leading class activities. The results were displayed as posters, which were evaluated by the class. The whole process was videotaped and analyzed. Creative thinking of the teachers was assessed using strategies described above.

3. Data Collection

Evidence for creativity and capabilities of teachers was collected using the following methods: (a) observation of class activities (in person and on videotape); (b) reports of peer reflection toward class activities; and (c) portfolio assessment (Coleman, 1994; Wang, 1997a,b; Wang & Hsieh, 1997b).

4. Data Analyses, Discussion, and Findings

To meet the purpose of this study, the data collected were analyzed for how the author modeled instructional strategies (MIS), for what instructional scaffolding strategies (IS) the learner used to lead the class, and for performance indications (PI) of creativity that the participants developed. The abbreviations MIS, IS, and PI are used in the following data analyses.

At the beginning of the activities, three scenarios (MIS.1), vignettes (MIS.2), challenging questions (MIS.3), and paradoxes (MIS.4) were presented as anchor contexts to promote the learners' open-ended thinking about the greenhouse effect issue. Scenario One was about the greenhouse effects caused by an adequate constant equilibrium concentration of carbon dioxide due to the balance between photosynthesis and respiration. Scenario Two showed forests being devastated. Scenario Three exhibited air pollution caused by vehicles and factories. STS vignettes consisted of a short illustrative story, challenging questions, and paradoxes related to the "greenhouse effect" and "global warming." Learners were encouraged to find problems related to the issue. This was a brain storming activity (MIS.5) to motivate interest and promote the issue awareness. An example of the questions raised is:

> What sources of energy should we use to avoid global warming?

The students were instructed to take time to (a) reflect (MIS.6) on what they had heard and seen and (b) map (MIS.7) out their thinking. During the activities, the learners were asked to extend, elaborate, and refine (MIS.8) their maps. The students, working in small groups (five members), collected, organized, discussed, and interpreted data and information to extend their understanding of the greenhouse effect issue and relevant problems (small group learning)(MIS.9). An example of the maps drawn by a learner showed that he was aware of (PI) the greenhouse effect issue. He read out:

> Vehicle exhaust, denuded forests...have an unbalanced greenhouse effect... in turn cause global warming, sea level elevation...

Role playing and debating (MIS.9) were arranged to help each group see problems from different viewpoints and redefine each problem (P2.2). The students engaged in role playing (MIS.10), suggesting, and debating (MIS.11) alternative approaches to solve social issues using scientific and technological methods (class learning)(MIS.12). The roles played were those of consumers, scientists, manufacturers, EPA personnel, and forestry administration personnel. The students discussed and debated the questions raised:

> Petroleum will be exhausted in 50 years and coal in 500 years. What should we do about energy resources?

Activities introduced the learners into deeper, open-ended thinking. Role playing evoked their imagination and inspiration, leading to ideas for problem solving; it also evoked their awareness of the importance of creative effort in personal living. The experts and manufacturers group proposed:

> To investigate solar energy, alternative energy, and new energy sources. To invent new products using wastes....We need creative ideas.

The Ministry of Transportation and Environment Protection Agency suggested that:

A public transportation system should be constructed, the number of vehicles and exhaust gas should be controlled, and public awareness must be promoted. The Bureau of Forestry suggested that:

> More plantations must be encouraged and illegal cutting must by prohibited.

The consumer group suggested that:

> As customers, we should think harder about how to reuse and recycle resources and reduce waste.

Brain storming and peer learning (MIS.10) expanded their knowledge to domains other than chemistry. They further discussed the potential effects on individuals and society of applying possible solutions:

> Life quality improves, but taxes increase as prices go up.

The mapping helped them link, cluster, organize, construct, modify, and elaborate (P2.1) their cognitive frameworks to better understand (P2) the situation and find problems (P1.2) for further study (shown in the maps). Each group identified an STS topic for further investigation (PI.2). They designed (IS.1) class activities and instructional strategies for scaffolding (IS.2), which were presented to the class orally and in written form (P2.4). Then, each group took turns leading (IS.3) class activities.

For example, one leader group identified garbage as a problem (P1.1) for further investigation and decided to explore ways to "reduce the amount of garbage by using proper ways of wrapping and shaping containers and packages (P2.2)." This group used card brain storming (IS.4)(P3.4) as a divergent thinking skill to find proper ways (P3.1) of packing and wrapping to reduce the amount of garbage. Although fluency in thinking is no longer considered synonymous with creative ability, it is, nevertheless, an important component of creativity (Runco, 1991). Fluency in divergent thinking was analyzed (MIS.13) as follows. The leader group asked all the participants to write or draw the package shapes as fast as possible, using exactly 3 minutes. Items of ideas for individuals ranged from 10-15 for 3 minutes. Each group and each person examined their items where members, in turn, read aloud (IS.5) their items, while the other individuals could get ideas and add them to their lists. The total number of items of Group A was 51; Group B, 54; and Group C, 45. The same operation among the four groups resulted in 123 items. The results indicated that (a) the fluency for these individuals was in the normal expected range (Buzan, 1988, p.120); and (b) small group learning and class learning promoted their divergent thinking. (Buzan stated that the average was 2-8 items per minute, where 8 was unusually high, and 12 was very rare.)

Flexibility was analyzed (MIS.14) in terms of the four dimensions of thinking: experience based, analogical, analytical, abstract. The results were, respectively: Group A, 39, 8, 5, 5; Group B, 21, 16, 13, 4; Group C, 22, 16, 7, 0. The results showed that for all four groups experience based thinking was predominately used, followed by the other dimensions in decreasing order.

Examples of experience based thinking were classified as life related and chemistry experiment related:

> Life related: Glass bottles, soft drink plastic bottles, jars with lids, plastic milk jugs, shallow dishes, ceramic cups, plastic ziplock bags, wrapping cloth, bamboo baskets, boxes, carts, toothpaste tubes, cans, aluminum foil....
>
> Chemistry experiment related: Erlenmeyer flasks, petridishes, round-bottomed flasks, beakers, measuring cylinders, pipettes....

The items related to chemistry experiments reflected the academic background of the participants.

> Examples of analogical thinking were as follows: scarves - wrapping cloth - handkerchiefs - wrapping paper - lotus leaves ; plastic bags - ziplock bags; shallow dishes - watch glasses; cylinders - burettes; pipettes - sample syringes....

Examples of analytical thinking were observed in functionally correlated pairs as follows:

> Tea kettles - tea cups; soup bowls - spoons; pots - serving spoons; funnels - flasks; measuring cylinders - beakers etc.

Examples of abstract thinking were as follows:

> Spray to form film to wraparound an object.
> Brush liquid on an object to form film to wraparound.

An idea suggested by the leader group for a way to wrap objects was to "spray to form film to wraparound an object." Obstacles (P3.2) of the design are that the package should be (a) safe, (b) hygienic (for food), (c) attractive, (d) informative, (e) inexpensive, and (f) complying with green issue requirements. Examples of comments were as follows:

> Packages must contain necessary information such as the contents of the package and expiry date. Packages should be recyclable and of minimal bulkiness. Packages must be secure and safe. Food packaging must be hygienic. Packages must be attractive to customers. Packaging should not cost very much.

The leader group took the following steps for further studies: (1) use flow charts (IS.6) as a thinking tool to develop unusual ideas into useful ones (P3.3); (2) evaluate the consequences of the proposed plan, considering all the measures against the obstacles mentioned above as well as resources, cost, time, and space (P3.5)(IS.7); (3) identify rigorous and important standards or criteria the invention must meet (P3.6); (4) write up (a) designed procedures for an STS exploratory experiment and (b) instructional strategies for scaffolding (P3.4); and (5) present the plan for class evaluation (P3.7). The leader group considered the following:

> There are a couple of ways to change paper to a solution to spray, but the solvent must evaporate easily to form film.

Participants other than the leader group asked questions, criticized, and discussed the design. The leader group defended and revised the design. The design proposed by the leader group was as follows:

> Used paper can be chemically converted to cellulose acetate; its acetone solution can be sprayed on the object and will form a thin film and wraparound after the acetone solvent evaporates.

This design was evaluated on the merits of products for (a) originality (P5.1), (b) tangibility (P5.2), (c) scientific thinking (P5.3), (d) scientific skills (P5.4), (e) dramatic value (P5.5), and (f) acceptability (P5.6). The class ruled that the idea met criteria (a), (b), (c), (d), and (e), leaving (f) controversial. One participant said:

> Acetone used in spraying would cause air pollution; film wrapped package would be fragile and unattractive.

The designed activities were found effective on the evidence collected for (a) performance indications of creativity, and (b) teacher capabilities developed. In other words, the activities were able to significantly improve the preservice teachers' creativity and cultivate their professional capabilities.

IV. Conclusions and Suggestions

In this study, a dynamic curriculum framework and a three-stage teacher development program were synthesized based on the works of this author and others, and developed through action research. The framework provided a way of thinking for teacher educators and/or teachers for (1) identifying thinking skills to be used, and (2) designing, organizing, and sequencing STS activities for professional development.

The case study shows how we used five-phase procedure with 22 processes as a dynamic learning procedure. Assessment tasks were used to find evidence of performance indications of creativity and to evaluate the effectiveness of instruction for first timers in this type of activity. The activities designed were found effective on the evidence collected for (a) performance indications of creativity, and (b) teacher capabilities developed. In other words, the activities were able to significantly improve the preservice teachers' creativity and cultivate their professional capabilities. From these activities, we also found that: (1) designing STS exploratory experiments was an effective way to cultivate creativity; (2) supervision must be ongoing for developing creativity; (3) teachers must be skilled in scaffolding activities; (4) all affected parties must be involved in developing programs designed to cultivate the capabilities of teachers; and (5) the creativity indicators (performance indicators) for judgment must be defined, communicated, and understood by the affected parties.

Everyone has creative potential at his or her own level of intelligence; continued practice in using creative approaches should lead to ever-increasing proficiency in creativity. Teachers are the key to success in science education reform. To implement programs related to creativity, teachers must be aware of the importance of creative effort - in learning, in the profession, in scientific pursuits, and in personal living. Becoming an effective creative problem solver is a continual process that stretches from classroom learning and real life experience from the kindergarten years to the end of the life span. These types of STS exploratory experiments can substantially improve preservice teachers' creativity and cultivate their professional capabilities in developing creativity. The author suggests that more action research should be undertaken to stimulate activities so that learners can experience in a real world situations to develop science literacy along with the capabilities of creativity, higher order thinking, decision making, and problem solving.

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經由 STS 探究實驗設計培養教師開發學生之創造力

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摘　要

本研究培養教師，使其能透過 STS 探究實驗設計，開發學生之創造力。著者設計具有彈性的課程架構，包括上述各項創造力要項的五層面與 22 過程之學習程序，作爲主要學習及評量內涵，並設計三層次教師成長方案，用於規劃學習活動。本研究進一步經由課程實驗試教之行動研究、探究：(a) 找出創造之表現指標之證據；(b) 由上述設計之課程及教師成長方案第一層次而培養教師之有效性。著者設計錨式模組，促使學生以小組及班級合作學習模式，學習基本思考技法：腦力激盪、角色扮演、辯論和畫思考圖等之後分組。各小組確定 STS 題目、設計探究實驗及鷹架策略，並向全班提出、接受全班的挑戰和批評。帶動小組答覆、辯論和修改。各小組輪流帶動班級活動，將成果以壁報展示，並由全班同學評鑑之。整個過程以直接觀察、錄影記錄、學習歷程檔案、和同儕評量等方法搜集資料。資料經分析後顯示：(1) 在流暢性評量方面：(a) 每一個人的擴散性思考能力是在正常範圍內；(b) 小組及班級學習提升擴散思考。(2) 柔軟性思考分爲經驗取向、類比、分析、抽向四層面；所有小組以經驗取向思考爲主（包含生活及化學之實驗思考，顯示其專業背景）；(3) 個案小組之設計，以 (a) 獨創性、(b) 具體性、(c) 科學思考、(d) 科學技能、(e) 吸引注目性及 (f) 接受性評鑑。全班評定個案小組之設計符合 (f) 以外的所有基準。這些經驗和成果能促進職前教師之創造力及培養其開發學生之創造力。

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Aboriginal Children's Alternative Conceptions of Animals and Animal Classification

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Abstract

This study examined aboriginal children's conceptions of animals and animal classification. Thirty-six students were selected from the 2nd, 4th, and 6th grades of two elementary schools in Hualien. A clinical interview and a classification task, involving the sorting of pictures of animals into major classes, were administered. The results indicated four forms of classification thinking: (a)living; (b)non-living; (c)animal, with scientifically acceptable attributes; and (d)animal, with scientifically unacceptable attributes. Children in all grades usually used a combination of the last two forms. Movement and eating were the most commonly used attributes for identifying animals. The label "animal" was usually applied to large, terrestrial mammals found in zoos or in the jungle. Humans were not categorized as animals by a substantial number of children, particularly in the lower grades. Although some of those in the higher grades were aware that humans were animals, the reasons given were irrelevant to animal attributes and improperly derived from the biological concept of "evolution". It was also found that the children's understanding of biological classification was generally poor. Even when the children could classify an animal instance as a subset of "animal" correctly, they still tended to consider it as a "non-animal" set. It seems that the children considered the subsets of animals as comparable sets to the set of animals.

Key Words: aborigines, animal, conceptions of animals, classification

I. Introduction

1. Research Background

In the study of the conceptions of animals and animal classification, research has pointed out that children have many alternative conceptions of class concepts. For example, Natadze (1963) found that children mistook bats for "birds", and dolphins for "fish". Voelker (1972) found that children better understood the concepts "mammal" and "fish", but were not familiar with the concept "invertebrate". Bell (1981a) found that children confused the attributes of animals with those of living things. The scope of animals was limited to those found in homes, farms, and zoos. Under "living things" there was only one herarchical level, with insects, fish, birds, and people all seen as comparable sets to the set of animals (Bell, 1981b). Braund (1991) pointed out that the narrowness of children's conceptions of animals also extended to the subclasses of animals. For example, having a hard shell made an animal "vertebrate"; having no appendages made one "invertebrate". This kind of misconception about animal classes was found in research done on all age groups. While children might have different kinds of misconceptions, the condition was nevertheless pervasive (Ryman, 1974a, b; Trowbridge & Mintzes, 1985); even college students or pre-service teachers had such misconceptions (Trowbridge & Mintzes, 1988; Chen, Huang, & Wang, 1994).

Cross-cultural comparative research, both in this country and overseas, has proven that children from different cultural environments have different conceptual comprehension (Billeh, 1969; Chao, 1975; Chen, 1983, 1987). And within a single language and culture, urban and rural children differ in their acquisition of scientific concepts (Weinbrenner, 1969; Richard, 1970; Chen, 1983, 1987, 1989), and also exhibit intrinsic differences in the concepts they acquired (Tamir, Nussinovitz, & Nussinovitz, 1981). Tema's research (1989) also pointed out that urban/rural differences

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could result in different thinking patterns towards the animal concept. In our previous research on conceptions of living organisms (Chen & Ku, 1997), we also found that aboriginal children showed different abilities in identifying "living organisms" and "living things"; and their classification of living organisms tended towards a single-level structure. Moreover, although aboriginal children receive a standard Chinese education, they live in a mostly natural environment with wildlife as one of their food sources. It is conceivable, therefore, that their experience and knowledge of animals should be different from that of non-aboriginal children. It follows that it would be beneficial for future elementary school course design and teaching to investigate aboriginal children's ability to recognize and classify animals.

2. Purpose of the Research

The purpose of the research was threefold: (1) to understand aboriginal children's alternative conceptions of animals; (2) to study the attributes used by aboriginal children in classifying "humans as animals or non-animals"; and (3) to understand aboriginal children's animal classification and their comprehension of the subclasses of "animal".

3. Limitations of the Research

The measurement criterion used was the children's classifying behavior. That is, we studied the children's cognitive perspectives based on the generalizations and discriminations of their classification schemes. Under these limitations, the scope of the research was delimited as follows:

(1) Our study dealt only with the familiarity of concepts, not how they were formed.
(2) "Aboriginal children" were limited to children of the Taya tribe only. They did not include children of other aboriginal tribes.
(3) The content of the children's conceptions of animals was limited to what they remembered during interviews, which may not be representative of their full knowledge.

Based on the purposes of this study, we chose Mandarin Chinese as the language of interview.

II. Method

1. Subjects

The subjects of this study were 36 children in the 2nd, 4th and 6th grades of two elementary schools. These schools were located in a traditional Taya village in a mountainous area of Hualien. As in most aboriginal schools of eastern Taiwan, there is only one classroom for each grade with 20 or fewer students in it. Selection of students was performed randomly by the researcher. Three groups of 12 students, each with an equal number of boys and girls, were selected from the 2nd, 4th and 6th grade classrooms.

2. Research Framework

Based on its purposes, this study collected data through individual interviews conducted in two phases. Accompanied with the interviews, two instruments were provided.

Phase one: conceptions of animals

Scope of comprehension of the "animal" concept
↓
Definition of "animal"
↓
Comprehension of the "animal" concept
(1) animals
(2) moving man-made objects
(3) moving natural objects

Phase two: animal classification
1. animal classification
(1) fish
(2) mammal
(3) insect
(4) bird
2. basis for the animal classification
↓
3. verification of animals

3. Instruments

Two instruments were used in this research.

A. Test on the Comprehension of Animal Concept (Task I)

Using the test items of our previous research on the children's conceptions of "living organisms" (Chen & Ku, 1997) and Bell's research design (1981a) as references, we selected and purchased 12 flash cards of animals and moving, non-living objects as the content of the test. They included:

(1) 6 animal items: tiger, snail, fish, girl, beetle, and snake.
(2) 6 non-living items, 3 of which were man-made objects: car, boat, and alarm clock; and 3 were

natural objects: cloud, lightening, and sun. During our interviews we randomly selected one card from the above 12. Then, following a predesigned routine, we asked "What is this?" If the child did not know, we told him/her the answer. Then we asked "Is it an animal?" "Why?"

B. Test on the Classification of Animals (Task II)

Using Trowbridge & Mintzes' classification cards (1985) as a reference, and taking into consideration what animals were familiar to the local children, we selected the following 15 animals as our testing instruments: cockroach, butterfly, sparrow, fish, human, dog, bat, turtle, frog, shrimp, squid, snake, earthworm, and spider. All the cards were mixed together in one stack. During the individual interviews, we asked the children to separate them into piles of "fish", "mammal", "bird", "insect", and "none of the above". After they did that, we asked them the following questions: "Why do these belong to the *x* group?" "Any other reasons?" "Why are these none of the above?" "Any other reasons?" When we finished these questions, we put the cards into one stack again and asked the children to separate them into piles of "animal" and "non-animal". We then asked them "Why are these animals?", and "Why are these not animals?".

III. Results

1. Aborignial Children's Conceptions of Animals

A. Examples of Animals

When asked to give 5 examples of animals, all the childern could correctly do so. A breakdown of the examples they gave showed that 60% were mammals, 12% were birds, 12% were insects, 10% were reptiles, and 2% each were fish, molluscs, and non-insect arthropods. This result showed that the aboriginal children had the greatest contact with mammals in their daily experience.

Although children in each grade gave different percentages of the animal items, the most frequently named animals were the same. They were, in the order of frequency of use, tiger, lion, elephant, monkey, dog, leopard, snake, bird, and cat, etc. These were grouped roughly into the following three categories:

(1) Jungle or zoo animals: tiger, lion, elephant.
(2) Wild animals living close to human environment: snake, bird, mouse, fish.
(3) Domestic animals: dog, cat, cow, rabbit, chicken.

B. Definition of Animal

Of all the definitions of animal given by children in each grade, less than half were scientifically accepted attributes. Their definitions were mixed with numerous animal attributes or living organisim and non-living organism attributes that are not acceptable to biologists. For example:

"Living in the mountains, living in the woods, living in the dark, living in trees, living in the zoo." (2s1).
"Can walk, can run, can fly, can eat, not unmoving like a solid object." (4s3).
"Can move, has life, can bear children, can breathe." (6s2).
"Has life, can eat plants." (6s10).
"Because they can move, ... not like people, ... because people are evolved from apes, ... they are from dinosaur's time, they have hands and feet, can move ..." (6s1)
"Animals are not people, they are not sun either, people are not animals either." (6s1)

Children's definitions showed that:

(1) The greatest number of children used the attributes eating and movement, including 13/36 and 11/36 of all subjects respectively. These attributes were used more often by the 4th and 6th graders.
(2) Children's definitions of animal included the use of diverse, non-scientific animal attributes. The descriptions they gave were based mainly on an individual animal's characteristics, such as appendages, habitats, external forms, etc.
(3) Some of the 6th graders used the following living organism attributes: life (3/12), reproduction (2/12), breathing (1/12). Fewer 4th graders used these attributes. Among the 2nd graders, only one (1/12) used "grow up" but none of the other living organism attributes.
(4) A few of the children (mostly 4th and 6th graders) used anthropocentric attributes. These attributes were mainly based on a comparison with humans, or used human feelings as a reference point.

C. Identification and Attributes of Animals

(1) Identification of Animals

When shown 12 familiar animal, man-made, and natural items, children's identification results are shown in Table 1.

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Table 1. Responses by Aboriginal Children in Each Grade for Animal and Non-animal Items.

Pcture	Grade (no. of children)			
	All (N=36)	2 (N=12)	4 (N=12)	6 (N=12)
Girl:				
Animal	12	–	5	7
Non-animal	22	12	6	4
Don't know	2	–	1	1
Fish:				
Animal	33	9	12	12
Non-animal	3	3	–	–
Don't know	–	–	–	–
Snake:				
Animal	34	11	12	11
Non-animal	2	1	–	–
Don't know	–	–	–	1
Beetle:				
Animal	31	9	11	11
Non-animal	4	3	–	–
Don't know	1	–	1	1
Snail:				
Animal	29	8	11	10
Non-animal	6	4	–	2
Don't know	1	–	1	–
Tiger:				
Animal	36	12	12	12
Non-animal	–	–	–	–
Don't know	–	–	–	–
Sun:				
Animal	–	–	–	–
Non-animal	36	12	12	12
Don't know	–	–	–	–
Cloud:				
Anima	–	–	–	–
Non-animal	36	12	12	12
Don't know	–	–	–	–
Lighting:				
Animal	–	–	–	–
Non-animal	35	11	12	12
Don't know	1	1	–	–
Boat:				
Animal	–	–	–	–
Non-animal	36	12	12	12
Don't know	–	–	–	–
Car:				
Animal	–	–	–	–
Non-animal	36	12	12	12
Don't know	–	–	–	–
Alarm Clock:				
Animal	–	–	–	–
Non-animal	36	12	12	12
Don't know	–	–	–	–

It was indicated in Table 1 that:

(a) For animal items except the "girl" item, most of the children could identify them as animals. Except for the "tiger" item, the 2nd graders generally made the most mistakes.

(b) Children generally did not think of humans as animals. None of the 2nd graders thought of humans as animals. Nor did almost half of those in higher grades.

(c) Man-made and natural items, even if they could move, were not identified by children as animals. Obviously, the movement of a non-living organism is different from that of an animal. Either children could understand this intrinsic difference, or non-animal characteristics were not consistent with their concept of animal prototypes.

(2) Attributes of Animals

An analysis of the children's animal identification attributes is shown in Table 2. Table 2 shows that:

(a) The attributes used by children in identifying animals were quite diverse. The most frequently used attributes were: movement, attacking, eating, external form, appendages, habitat, and behavior. Children did not use just one single attribute to identify animals. Instead of the critical attributes of animals, they used individual characteristics to identify each animal. The following excerpt of an interview with a 6th grader is a good example (6s1):

"Why is a snail an animal?"
"It can move, ... it has life..."
"What else?"
"I don't know, ... not like people,... it can live in water, ... no, it can hide in its shell."
"Why is a beetle an animal?"
"Because it can move too, ... because it is an insect, ... it has 6 feet, ... its body is not the same as human's, ... because it can eat."
"Why is a fish an animal?"
"It can move too,... fish lives in water, ... it can go under water for a long time, ... can be eaten by people, ... it has no hands or feet, ... just fins, and lives in water ..."

(b) As with the attributes used to define animals, the aspects used to identify animals can also be classified into the following three groups: attributes of animals, attributes of non-animals, and classes. Their contents are also similar, except that the attributes used to identify animals tend more to be an individual species' unique characterisitics, and the attributes were compared with human,

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Table 2. Reasons Used by Aboriginal Children for Identifying Objects as Animals

Reasons	Grade (no. of children) All (N=36)	2 (N=12)	4 (N=12)	6 (N=12)
Attributes of animals:				
A. Scientifically acceptable:				
Eating	24	6	9	9
Moving	31	9	11	11
Excretion	1	–	–	1
B. Scientifically unacceptable:				
Appendage	18	5	6	7
Habitat	13	4	5	4
External form	24	8	8	8
Attacking	26	8	8	10
Appearance	19	5	5	9
Sound	5	2	1	2
Hair(Body covering)	8	3	3	2
Body color	7	2	4	1
Behavior	11	3	5	3
Texture	4	2	1	1
Attributes of non-animals:				
A. Living:				
Life	5	–	1	4
Reproduction	7	–	2	5
Breathing	2	–	1	1
B. Anthropocentric and functional:				
Unlike human	3	–	1	2
Size	1	–	1	–
Temperament	1	–	1	–
Lovability	1	–	1	–
Like human	1	1	–	–
Created by God	2	–	1	1
Used by humans	6	1	1	4
Using classes	4	1	1	2

i.e. anthropocentric and functional attributes. For example:

" A fish is an animal, because it can swim, ... very cute", "Not like people",
" It has scales, ... has a tail, people do not have tails, ... its body is prickly, ... it has fins on its sides, ... its mouth is very small." (2s7)

(c) The 6th graders used more attributes of living organisms in identifying animals, indicating confusion between living organisms and animals.

(d) Children in all grades used both scientifically acceptable and unacceptable attributes in identifying animals, indicating that classroom teaching had not been very effective.

(3) Identification and Attributes of Humans

(a) Humans as Animals

In the identification of humans, only the 4th and 6th graders correctly identified "girl" as an animal. All the 2nd graders believed that a person is not an animal (Table 1). However, the attributes they used were not consistent. The 4th graders and a few of the 6th graders used living organism, human or religious reasons to explain why humans were animals. In their identification process, they usually started by identifying a person as an animal, often giving reasons that were human behavior characteristics. They proceeded from an anthropocentric point of view, often digressing from the subject. Sometimes they were not even aware that they were being self-contradictory. For example:

" She is made by Jesus, ... because she can move, ... she can also think of animals", "Her appearance is very lovely, ... she is going to eat ..." (4s1)
" She can walk, and has hair, ... she has body hair too ..., ok." (6s5)

Some of the 4th graders considered "girl" to be an animal, but the reasons they gave emphasized the differences between humans and other animals. This shows the contradictory idea that "Humans are animals, but are not the same as animals":

"Tell me, why is the little girl an animal?"
"She likes to eat animals, ..."
"Then are you a little girl?"
"Yes!"
"Are you an animal then? ... Why?"
"I can't think of it"
"It's all right. Think again. Why are you and I both animals?"
"Because we like to eat different things, ..."
" And?"
"We don't live with animals, ..."
"Anything else?"
"Because our nose and eyes are different from animals', ... and chest, ... and many other different things, ..."
"Give me some examples"
"Very cruel, very bad, also some are good, can't tell them apart ..."
"That's why we are all animals, is that it?"
"Yes." (4s5)

Although more than half of the 6th graders could identify a person as an animal, the reasons they gave were not directly connected with animal attributes. Almost all of them cited the concept of "evolution" in a non-biological sense, thinking that the reason why a person is an animal is because humans came

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Table 3. Reasons Used by 4th and 6th Graders to Identify Humans as Animals.

Reasons why humans are animals	Grade (no. of children) All (N=36)	2 (N=12)	4 (N=12)	6 (N=12)
1.Evolved from apes	6	–	–	6
2.Has hand & feet and external structure	4	–	2	2
3.Human behavior	3	–	1	2
4.Created by God(Jesus)	2	–	1	1
5.Can eat	2	–	1	1
6.Has blood	1	–	–	1
7.Has life	1	–	–	1
8.Bear childern	1	–	1	–

from apes, and apes are animals, so humans are also animals.

Some children switched from thinking that humans are not animals to thinking that humans are animals during their interview:

"Then how about the little girl? Is the little girl an animal?"
"She is human, she won't bite people, ... not the animal, ... she will not kill animals."
"Anything else?"
"She should be an animal!"
"Ok, then tell me why little girl is an animal."
"There were no people before earth, no people living, only the dinosaurs, then the apes became people".
"Oh, so people are animals?"
"Umhm." (6s8)

The children's reasons for identifying humans as animals can be summarized in the following 8 items (see Table 3). These show some characteristics of the aboriginal children:

(i) Though the children knew that humans are animals, the attributes they used were almost entirely scientifically unacceptable, and some were even anthropocentric and functional attributes.

(ii) The reasons given by the 6th graders were almost all derived from a concept of "evolution" in a non-biological sense, and were entirely irrelevant to animal attributes. This shows that there exists a gap between human and animal concepts. The children could not make use of critical attributes to generalize animals.

(b) Humans as Non-animals

Table 1 and 3 show that most children, especially those in the lower grades, believe that a person is not an animal. Their reasons are as follows:

Table 4. Reasons Used by Aboriginal Children in Each Grade to Identify Humans as Non-animals.

Reasons why humans are not animals	Grade (no. of children) All (N=36)	2 (N=12)	4 (N=12)	6 (N=12)
1.Behaviors are different	17	9	4	4
2.Is human (a special class)	15	6	5	4
3.External form is different	12	9	3	–
4.Living at home	2	2	–	–

"Is the little girl an animal?"
"No, because she lives at home, she picks flowers in the garden", "and she is human too".
"Not an animal, because her eyes are not like animals', nor her feet, nor her hair, nor her nose or mouth ..." (2s3)
"Not an animal, because she is human, ...", "Not like the animals, can not run like the animals ...", "She has no tail", "She can not run horizontally like an animal ...", "Not like the animals..., she has mouth, she can talk, animals can not talk." (2s8)

The reasons given by the children can be summarized into 4 kinds. However, the children generally did not use just one single kind of reason. More often they used a combination of them. The numerical distribution of use according to grade level is as the Table 4.

Table 4 shows that:

(i) The belief that "humans are animals" was quite common. Nearly half of the 6th graders still had this misconception.

(ii) Humans were thought of as a class of their own. Human behavior, life style, and appearance were all different from those of other animals. Therefore, it was indeed difficult to include humans in the class of animal. This was especially true for the 2nd graders. Their reasons included all 4 kinds.

(iii) The reasons cited by the 4th and 6th graders were fewer than those of the 2nd graders. They were mainly about the class of humans and behavior patterns, indicating a stereotypical belief that humans are a special class.

D. Identification of Non-animals and Their Attributes

Shown non-animal items, children of all grades could correctly determine that movable man-made or natural objects are not animals (see Table 2). Movement obviously was not the single critical attribute in identifying animals. Children might not be able to give non-animal attributes, yet they could all give reasons why the non-animals were different from animals. For example:

> "Why is the car not an animal?"
> "It has wheels, ... can turn, ... can also move ..."
> "Anything else?"
> "It needs gas too, ... can carry things too, ... can carry people too, ... has lights that shine too, ..." (4s4)
> "Why is the sun not an animal?"
> "Because it lives in the sky, ... we don't know when it will come out, it lives in a different place from ours, ... because sun, ... it gives very hot light, don't know! ..."
> "Think again."
> "It does not eat things ..." (4s5)

From the above reasons given by children we see the following:

(1) Children did not make use of animal attributes to differentiate natural or man-made objects from animals. Instead, the reasons they gave were based on the individual objects' attributes and characteristics.

(2) Children in all grades identified natural or man-made objects as non-animals because of their differences from animals. This indicates that the children were comparing these objects with the existing prototypes they had of animals.

(3) Some of the objects possessed attributes that were similar to animals' characteristics, such as movement or similar external forms. The children, nevertheless, knew that these were not really the same as those of animals. This indicates that the children were not using one single attribute to differentiate animals and non-animals.

2. Animal Classification by Aboriginal Children

A. Classification of Animal Sub-classes

We examined children's comprehension of animal classification by asking them to divide the 15 animal cards into insects, birds, fish, and mammals. The results are listed in Table 5.

Table 5 shows:

(1) Children in all grades made incorrect classifications in all subclasses. Performance did not improve with grade level.

(2) Those children who could place each animal item in the correct subclass did not necessarily classify them correctly as animals.

(a) Classification of Insects

In the classification of insects, Table 5 shows that over half of the children classified an earthworm, and a spider as an insect. And nearly 10% in each grade classified a turtle, a snake, or a frog as an insect.

An analysis of the attributes the children mentioned gives us the following order of importance: size, habitat (environment), activity behavior, eating behavior, and number of feet. This reflects the children's concept of insects as "animals that have small size, many feet, can crawl, and live on land".

(b) Classification of Birds

Table 5 shows that 1/4 of the children mistook the butterfly and the bat for birds. As for the sparrow, and duck, though both were identified as birds, children thought of them in different ways. The sparrow was closer to the children's prototype of a bird than a duck. The attributes of birds were chiefly: flying and wings. None of the children used feathers as an attribute. So "has wings and can fly in the sky" was obviously the children's prototype for birds.

(c) Classification of Fish

Table 5 shows that the children in all the grades classified a turtle, a shrimp, or a squid as a fish. An analysis of the children's responses shows that they used living in water and swiming as the attributes of fish. The children's idea of fish seemed to be "animals that live in water and can swim".

(d) Classification of Mammals

Table 5 shows that the children had the greatest number of misconceptions about mammals. Although the children knew that nursing and viviparous are attributes of mammals, they did not actually have real-life experience of this and did not really know the meaning of these attributes. Therefore, they usually identified mammals subjectively instead of using their attributes. So there was a high rate of mistaking the turtle, snake, and frog as mammals.

B. Classification of Animals and Non-animals

After classification of insects, birds, fish and mammals, we asked the children to categorize the 15 cards into groups of animals and non-animals. Results indicate that the children could correctly identify subclasses but did not know that an animal belonging to a certain subclass should also belong to the class of animals (Table 5). The non-animal reasons they

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Table 5. Percentage of Classification Responses by Aboriginal Children in Each Grade.

Picture	Classified as : Insect	Bird	Fish	Mammal	Other	Animal	Non-animal
Insect:							
Cockroach							
	92	–	–	(8)	–	67	(33)
	75	–	(8)	(8)	(8)	50	(50)
	92	–	–	–	(8)	33	(67)
Butterfly							
	67	(33)	–	–	–	83	17)
	58	(25)	–	–	(17)	58	(42)
	58	(25)	–	(17)	–	58	(42)
Bird:							
Sparrow							
	–	83	(8)	(8)	–	83	(17)
	–	100	–	–	–	100	–
	–	100	–	–	–	100	–
Duck							
	(8)	58	(17)	(17)	–	83	(17)
	–	42	–	(42)	(17)	92	(8)
	–	17	–	(50)	(33)	92	(8)
Mammal:							
Human							
	–	–	–	25	(75)	8	(92)
	–	–	–	25	(75)	33	(67)
	–	–	–	58	(42)	83	(17)
Dog							
	–	–	–	83	(17)	92	(8)
	(8)	–	–	58	(33)	100	–
	–	–	–	75	(25)	92	(8)
Bat							
	(17)	(50)	–	17	(17)	83	(17)
	(17)	(42)	–	42	–	75	(25)
	(8)	(33)	–	42	(17)	75	(25)
Fish:							
Fish							
	–	–	100	–	–	72	(25)
	–	–	92	(8)	–	58	42)
	–	–	100	–	–	67	(33)
Others:							
Turtle							
	(33)	–	(25)	(33)	8	83	(17)
	(8)	–	(33)	(42)	17	92	(8)
	–	–	(17)	(50)	33	92	(8)
Frog							
	(42)	–	–	(42)	17	75	(25)
	(25)	–	(8)	(50)	17	83	(17)
	(8)	–	(17)	(42)	33	67	(33)
Shrimp							
	(17)	–	(67)	(17)	–	75	(25)
	–	–	(75)	(8)	17	58	42)
	–	–	(67)	(17)	17	67	(33)
Squid							
	(17)	–	(83)	–	–	75	(25)
	–	–	(67)	(8)	25	50	(50)
	–	–	(58)	(25)	17	67	(33)
Snake							
	(17)	–	(8)	(42)	33	58	(42)
	(42)	–	–	(25)	33	92	(8)
	(8)	–	–	(25)	67	75	(25)
Earthworm							
	(83)	–	–	–	17	58	(42)
	(67)	–	–	(8)	25	42	(58)
	(50)	–	–	(33)	17	33	(67)
Spider							
	(58)	–	(8)	(25)	8	58	(42)
	(75)	(8)	–	(8)	8	42	(58)
	(83)	–	–	(8)	8	42	(58)

* First, second & third number of each item correspond to 2nd, 4th, & 6th graders respectively.

**( )means incorrect classification.

gave were all an individual animal's characteristics, such as:

> "They do not have wings, ... nor ... pointed eyes, ... nor 8 feet, ..., they ... do not have pincers, ... nor shell." (2s1)
>
> "Because a spider is not like a dog, it can only lay eggs, eat, people eat, it does not bark like a dog, does not have 4 feet, an earthworm has no feet, it eats insects, ..., it is a fish, fish are not animals, ..." (4s3)
>
> "Because a fish can swim, not like them, ... people can not run, can not fly, can not jump, so it is not an animal" (4s10)
>
> "They are small in size, live in dirty places, ... people are people, not like animals ..." (6s7)

The excerpt above shows that the children thought of animal subclasses as independent from the animal class. A comparison with the previous test on animal identification (Table 6) shows that the children were relatively consistent with the "human" category, but were quite inconsistent with the other animals. When identifying animals alone, they could correctly identify them as such. Yet asked to identify animals after they had performed the classification of subclasses, many children identified animal items as non-animals. A further comparison of the fish and insect items used in both tests is shown in Table 7.

Table 6. Number of Children in Each Grade Who Answered "Not Animal" for Human and Other Animal Items.

Picture	Grade 2 (N=12) Task I	Task II	4 (N=12) Task I	Task II	6 (N=12) Task I	Task II
Human:						
Non-animal	12	11	6	8	4	2
Don't know	–	–	1	–	1	–
Other animals:						
Non-animal	4	8	1	8	2	9
Don't know	–	–	1	–	–	–

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Table 7. Number of Children in Each Grade Who Answered "Not Animal" for Fish and Insect Items.

Grade	Fish is not animal		Insect is not animal	
	Task I	Task II	Task I	Task II
2nd(N=12)	3 (2)	3	3 (2)	4
4th(N=12)	–	5	1 (1)	6
6th(N=12)	–	4	1	6

*Numbers in ( ) are the number of children who answered "not animal" during both the identification & the classification tasks.

Table 6 and 7 show that there was a distinct difference in the number of children between the two tests. The increased number came from children who could originally give the correct response, indicating that the children's animal concept comprehension was influenced by the subclass classification.

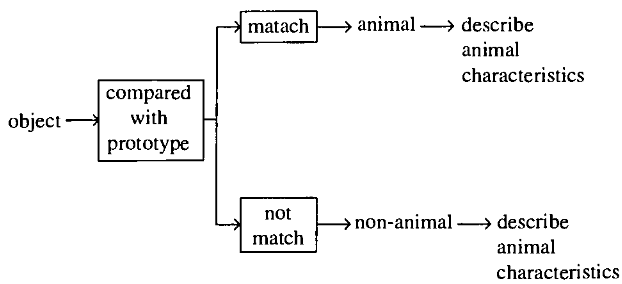
IV. Discussion

1. Conceptions of Animals

This study shows that most of the aboriginal children thought of things that "move, eat, attack" to be animals. Zoo and jungle carnivorous animals seem as if their prototypes. This is similar to the findings of Bell (1981a, b) and Trowbridge & Mintzes (1985, 1988) that most students limit their idea of animals to land-dwelling, four-footed mammals. However, from Trowbridge & Mintzes' samples, we see that American children used mainly household pets such as cats and dogs as examples, whereas our aboriginal children used mainly lions, tigers, and elephants. Obviously, Although children of eastern and western cultures may have similar views of animals, the domains of their conceptions are not quite the same. The western children placed more importance on the number of feet (Bell, 1981a, b; Trowbridge & MIntzes, 1985). They used familiar animals living close by as examples. Our aboriginal children paid more attention to attacking behavior, using as examples the animals they saw on TV or movies. This indicates that the aboriginal children either lacked confidence in their own life experience, or were misled by the mainstream culture into believing only large-sized, zoo mammals were animals.

2. Thinking of Animals

Rosch & Mervis' research (1975) pointed out that the children's classification was based on family resemblance, not on defining attributes. The results of this study also support this finding. When asked if an object was an animal, children tended to think about their own prototype. Objects that matched the prototype were animals, and those that didn't were non-animals. The reasons they subsequently gave were individual animal characteristics which had nothing to do with the classification of animals. The same characteristics could be used as reasons to sometimes categorize living or non-living things as animals and sometimes as not animals. For example, "fish moves" makes it an animal, "cloud moves" makes it not an animal; "tiger bites people" makes it an animal, "fish does not bite" makes it an animal too. The probable flow chart of responses is as follow:



From the reasons children used to explain why an object was an animal, we see that most children relied mainly on visual characteristics. What they used was a probabilistic perspective. All attributes were equally important in the children's view. And as the finding of Huang (1996) in non-aboriginal children, the attribute "movement" appeared most often. However, our aboriginal children obviously could distinguish the intrinsic difference between the movement of animals and that of non-living organisms. That's why the children did not think it contradictory that the same attribute could result in different classifications.

Some of the children gave reasons consisting of attributes common to both animals and plants. This is similar to the findings of Bell (1981a, b), Trowbridge & Mintzes (1985, 1988), and Tema (1989). This indicates that confusion of living organism and animal attributes is a common phenomenon. In our study, the higher the grade level, the greater the percentage of children who used living organism attributes. This supports the finding of our previous research (Chen & Ku, 1997) that upper-grade aboriginal children thought only animals were living organisms.

This study also found that children in all grades

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had a common self-centered tendency. The words they used often described personal feelings, used themselves as reference points, or made comparisons with humans, such as, "vnlike us", "unlike human", "can not talk", or "very cute", etc. This is similar to the South African children's anthropocentric thinking pattern described by Tema (1989).

3. Animal Classification

In his study of conceptions of animal classification, Natadze (1963) once pointed out that when the visual images of an object were not consistent with the essential features of its concept, not even the older children could become familiar with the concept. Our study shows that the children's animal classification was based mainly on their visual experiences. Hence, small animals that crawl on the ground are insects, those that fly in the sky are birds, and those that swim in water are fish. This supports the findings by Natadze (1963), Bell (1981a, b) and Trowbridge & Mintzes (1985, 1988). The textbook attributes, such as feathers for birds, gills for fish and hairs for mammals were rarely mentioned by the children, indicating the ineffectiveness of teaching. Moreover the increased knowledge of older children did not make them do better in animal classification. This supports research findings that misclassification of animals is common in all age groups (Ryman, 1974a; Trowbridge & Mintzes 1985, 1988; Braund 1991; Chen, Huang, & Wang, 1994). In the classification of humans, Although nearly half of the 4th and 6th graders thought that humans were animals, the reasons they gave had nothing to do with animal attributes. The 6th graders, especially, mainly used an improper evolutionary view in their explanation. This indicates that in children's view, human is a special class. Hence, how to relate humans with animals is indeed a challenging topic in teaching.

4. Humans as Non-animals

In our previous research on the aboriginal children's conceptions of living organisms, we found that a high percentage of aboriginal children thought that humans were not living organisms (Chen & Ku, 1997). In our research on conceptions of animals, the results also show that the aboriginal children not only thought that humans were not living organisms (36%), but also thought of humans as non-animals (61%) (Chen & Ku, 1997). In this regard, our research obviously does not support Bin Adbullah & Lowell's claim(1981) that children are better at generalizing lower level concepts than higher level concepts. Research done in other countries has also reported on the thinking that humans are non-animals. Bell (1981a, b) believed that this kind of thinking is derived from confusion between daily life language and scientific language. Tema (1989), on the other hand, believed it is derived from cultural background, which can be gradually replaced by animal-centerd thinking patterns by means of science teaching. Our study shows that the percentage of aboriginal children thinking humans are non-animals is much higher than that of foreign children. The reasons they gave were mainly that humans belonged to the class of humans, or that human characteristics and behaviors were different from those of other animals. According to Tema, this is an anthropocentric thinking pattern that is derived from cultural influence. We cannot be sure if this kind of misconception originates from the aboriginal culture per se. But in our mainstream culture, the colloquial terms "zoo (animal garden)" and "be nice to animals" both separate humans from animals. Therefore, the daily language of our social culture may be an influencing factor in causing this kind of misconception.

5. Children's Classification Performance

In our research, we found that children performed differently in the identification and classification of animals. In the case of non-human animal items, besides children who could not make the correct identification, even some who made the correct identification also classified them as non-animals. This kind of discrepancy in classification behavior indicates that the children's animal classification was influenced by the classification of animal subclasses. This may derive from a single-level classificatory thinking structure and an ignorance of animals' hierarchical relationship.

A. Concerning a Single-level Classification Structure

Bell's study (1981a,b) pointed out that New Zealand children placed fish, birds, reptiles, humans and other animals on the same level. In our previous research on aboriginal children's conceptions of living organisms we also found that children tended toward a single-level classification scheme. With the exception of humans, which were excluded from the system of living organisms, the other living organisms such as trees, birds, flowers, grass, animals, and plants were all placed on the same level. Perhaps it was this single-level classification structure that led children to ignore their animal prototype when doing classification and to treat fish, bird, insect, mammal classes as independent from the animal class.

B. Concerning the Hierarchical Relationship of Animals

In Piaget's research (Inhelder & Piaget, 1964), it was pointed out that children's categorical thinking did not become mature until they reached grade school level. Before that there was no logical relationship of class inclusion in their reasoning process. Their reasoning was based either on the part or on the whole. When they focused on the part, they ignored the whole. Ryman's research (1974a) also pointed out that insufficient class inclusion ability could influence the classification of animals. The present research shows that the factor that influences children's conceptions of animals is not physiological age, but the ability to establish proper hierarchical relationships among concepts. As they enter higher grades, their knowledge increases, and they learn more about subclasses, which perversely enhances their misconception that these subclasses are independent of the animal class.

V. Implications for Teaching Elementary School Science

Based on the results and conclusions of this research, we would like to suggest the following:

1. Strengthen the Comprehension of Basic Attributes of a Concept

Research has pointed out that children's alternative conceptions may interfere with the learning of concepts (Gilbert, Osborne, & Frensham, 1982). Our research shows that children rarely use the basic attributes of concepts in classification of animals. They rely mainly on visual characteristics as the attributes of animals. This indicates that the influence of school teaching is very limited. If teachers cannot clarify the difference between visual clues and basic attributes of a concept, then even children in the higher grades will still be misled by the visual characteristics. Therefore, the improvement in teaching should start from the basic attributes of concepts. Before introducing a concept, the teacher should clarify the meaning of the concept's attributes, or make sure that children fully understand the relationship between attributes and concepts. Only then can children avoid misunderstanding the concept.

2. Enhance Learning of Examples and Non-examples of a Concept

Bruner has pointed out that the acquisition of concepts is a process of discrimination and generalization (Bruner, Goodnow, & Austin, 1986). If students are not given sufficient examples and non-examples to discriminate and generalize, misconception could result. In the research of Trowbridge and Mintzes (1985), it was also found that insufficient examples of animals caused students to limit their animal concept to vertebrates, while insufficient non-examples caused them to group animals with similar external forms into one class. Therefore, enhancing the learning of examples and non-examples of concepts during teaching may eliminate the misunderstandings children have of animal concept and classification.

3. Enhance Teaching of Common Class Attributes

Our research found that regardless of their grade level, children were mostly unable to name the common attributes of animal and its subclasses. They tended to use an individual animal's characteristics or its differences from other animals as their basis for classification. Other research has also pointed out that most younger students can distinguish the differences between living organisms, but cannot state their similarities (Strommen, 1995). In an analysis of concept development concerning living organisms, animals, and plants in current elementary school natural science textbooks, Shao (1996) also pointed out that there was more attention given to the differences between concepts and examples in these textbooks, and less to the similarities. Herefore, it is necessary to put more emphasis on similarities among examples during teaching in order to enhance children's ability to generalize attributes.

4. Modify the Structure of Current Course Design for the Living Organism Concept

The design of the natural science course based on the living organism concept in our elementary schools begins with the most abstract class of "living organism", followed by the subclass concept of "animal" and "plant", and then the even lower class concept of "mammal", "bird", "fish" and "insect" (Shao, 1996). This kind of conceptual arrangement is not consistent with children's concept development from the concrete to the abstract. In our previous research on the living organism concept we also found that the aboriginal children tended to think of either animals or plants as living organisms (Chen & Ku, 1997). The reason for this was probably too early exposure to overly complex concepts, which caused the aboriginal children to become confused about the relationship among classes. Therefore, it might help children's comprehension of the animal concept to modify the course design and change the order of appearance of concepts.

5. Establish a Hierarchical Relationship among Concepts

There is a hierarchical relationship among class concepts based on their degree of generalization, and the different levels of concept are often programmed in different units or grades due to the curriculum design. Therefore, teachers should understand the place of a unit within the course arrangement and provide children with relevant concepts, giving them a chance to comprehend a hierarchical relationship among concepts. By clarifying supraordinate and subordinate relationships, it might be possible to eliminate the single-level classification thinking of the aboriginal children.

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山地兒童動物概念及動物分類之研究

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摘　要

本研究以花蓮山地國小二、四、六年級兒童共36名爲對象，研究山地兒童之動物概念與動物之分類，以個別晤談與動物圖卡之分類操 作收集資料。結果發現：兒童在動物的指認上有四種思考模式：(1)生物的，(2)非生物的，(3)動物且合乎科學的，(4)動物但不合乎科學的。不管低中高年級，兒童都以後兩種結合的思考模式爲主，而使用的 動物屬性大都以「運動」及「吃食」最多。兒童觀念中所謂的「動物」，大都指動物園或叢林的大型陸地哺乳動物，然而「人」則不爲多數兒童所認可，尤以低年級兒童爲然，中、高年級兒童雖可認同人爲動物，然而其概念大都來自不合適的生物演化的概念。本研究亦發現兒童的生物分類甚差，即使兒童可以將某一動物置於「動物」的某一 子類別之內，其仍然在動物分類時將此動物視爲非動物，顯示兒童有將「動物」之子類別與「動物」置於同一階層的傾向。

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A Study on the Technological Literacy of Elementary and Junior High School Students in Taiwan

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Abstract

The purpose of this study was to investigate the current status of technological literacy of Elementary and Junior High School students in Taiwan. A stratified random and cluster sampling method was employed in this study. A total of 3066 ninth graders from 44 Junior High Schools and 3420 sixth graders from 60 Elementary Schools have completed the technological literacy test developed by the researchers. The results show that : (1) These Taiwanese Junior High and Elementary students are fairly technologically literate especially in communication technology. The students are more literate in basic technology principles or theories than in practical and applicable knowledge. (2) At the Elementary level, female students scored higher than male students. But at the Junior High school level, male students scored higher than female students especially in terms of the application of technological knowledge. (3) The Junior High School students are very technologically literate in the fundamental section, but not in the advanced section. (4) Mass media, including newspapers, magazines, TV and radio, were evaluated as the most important sources of knowledge of technology for these Junior High School students.

Key Words: technological literacy, test

Introduction

The daily life of modern people is closely linked with technology. Our daily necessities, including means of transportation, architecture, and other facilities, are all closely bound up with technology. The widespread application of technology has brought us many benefits. For instance, it not only saves time, but also is more efficient to send messages via fax or the Internet, to withdraw or transfer money using an ATM, or to cook with a microwave oven or with an electromagnetic cooker. On the other hand, technology can have a negative impact on the environment and human life. For example, CFC, a coolant used in refrigerators and air conditioners, has thinned the ozone layer. Nuclear energy can also cause thermal pollution and radiation. The development of technology forges ahead at such a tremendous pace that new products, services and tools are constantly emerging. Living in a constantly changing era, we cannot assess technology or choose and use properly all sorts of technological products and services without a solid understanding of technology. As a member of the modern technological society, one needs to add some basic technological know-how, in addition to the traditional 3 R's, to one's basic abilities in life. This is what scholars refer to as "technological literacy". (Lee, 1992). Technological literacy can be described as "the possession of a broad knowledge of technology together with the attitudes and physical abilities to implement the knowledge in a safe, appropriate, efficient, and effective manner. Technological literacy requires that one be able to perform tasks using the tools, machines, materials and processes resulting from

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technology". (Dyrenfurth, 1984) As Benson pointed out, general knowledge includes three domains: technologies, humanities and sciences. Humans use three systems to adapt to their environment; a technological system, sociological system and ideological system (Hayden, 1989). This underscores the importance of technology. In the past, however, knowledge related to technology was rarely taught in schools. Many scholars (DeVore, 1986; Dyrenfurth, 1987; Hameed 1987; Hayden, 1989; Smalley & Brady 1984) called on their governments to emphasize education for technological literacy. The most effective way to equip citizens with technological literacy is through school education. Therefore, beginning in the 1980's, the USA and some European countries started pushing forward education for technological literacy in all levels of schools. In Taiwan, starting in 1990, the National Science Council sponsored studies on education for technological literacy to promote technological education and enhance technological literacy among all citizens.

The purpose of technological literacy education is to equip citizens with the basic ability to live in a modern technological society (Lo, 1993). More specifically, it aims to educate all citizens so that they may have general technological literacy, understand the meaning, content and trends of technology, experience the influences technology exerts on human life and lead the progress of society by partaking in matters related to technology (Huang, 1994).

Presently, compulsory education in the Taiwan ends with junior high school education. The education of technological literacy that students receive before graduation from junior high school may well be the key factor in determining whether they are equipped with the ability to adapt to the future technological society. An understanding of the students' level of technological literacy helps the planning and design of future curricula of technological literacy education. The ultimate goal is to equip all citizens with technological literacy.

Based on the above motivations, this study aimed to understand the level of technological literacy of elementary and junior high school students in the Taiwan area, so that it may provide a reference for future curriculum design and planning.

II. The Purpose and Scope of the Study

Based on the research motivations and background stated in the previous section, the study aimed to do the following:

1. Understand the current level of technological literacy among elementary and junior high school students in the Taiwan area.
2. Understand the differences of the level of technological literacy among elementary and junior high school students in the Taiwan area.
3. Understand how elementary and junior high school students in the Taiwan area acquire technological literacy.
4. Analyze the areas of technological literacy lacking among elementary and junior high school students in the Taiwan area so as to provide a reference for future curriculum design and planning.

The subjects under investigation in this study included only ordinary students in public junior high schools, public elementary schools and junior high divisions of public senior high schools in the Taiwan area. Special students (such as mentally-challenged and visually-challenged students) were not included in the study.

In addition, as the personnel, funding, and time for this study were limited, the study could only employ the questionnaire method to conduct a preliminary investigation of the cognition part of technological literacy.

III. Related Studies on Technological Literacy Tests

In other countries, numerous scholars and specialists have devoted themselves to the study of technological literacy. Domestically, however, it is still a relatively new field of research. Most studies were sponsored by the National Science Council and completed in the last few years.

Richter developed a scale at West Virginia University, the purpose of which was to measure the technological literacy of undergraduate students in terms of communication technology. The test, consisting of fifty-six multiple choice items with 4 choices and a correct answer, was based mainly upon the contents of Technology in western civilization and used as a tool to assess the level of technological literacy among undergraduate students (Shearrow, 1992).

In another study by Smalley & Brady (1984), using Delphi , nine criteria were set for the base of technological literacy. Based on the criteria, sample questions were selected, and a test that could indicate the level of technological literacy among American 12th-graders in the 1980's was developed. Three questions were developed for each criterion, and a test

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of technological literacy with 27 four-choice items with one correct answer was formed. According to Smalley & Brady (1984), the study adopted multiple choice items because they are a compromise between true-and-false questions and essay questions.

Hatch (1985) conducted a survey on the level of technological literacy of 16,000 students aged between 13 and 17. The findings of his research are as follows:

1. Operational definition of technological literacy: Technological literacy is a multi-faceted construct, which includes the ability to use tools (pragmatic aspect), to understand the problems brought on by technology (civil aspect) and to appreciate the meaning of technology (cultural aspect).
2. Instrument used to study technological literacy: Based on the data provided by NAEP (National Assessment of Educational Progress), the instrument consists of 53 cognition items, all of which are four-choice items with one correct answer and are able to present the aforementioned three aspects of technological literacy.
3. The difference analysis of the study shows that students with prior experience of machine operation score higher on the technological literacy test than those without any prior experience of machine operation.

With funding provided by NSF (the National Science Foundation), Miller (1986), conducted a telephone survey of 2000 adults, the purpose of which was to understand the familiarity of adults with technology. The results of the survey showed that the general public lacked clear understanding of the technology that influenced their daily lives. Miller indicated that under such circumstances, not much could be expected for the safe and efficient use of technological products and systems by the general public.

In Hameed's study (Hameed, 1988), based on the definition of technological literacy, test questions on technological literacy were selected from over 1,000 multiple-choice questions. This test covers four areas: i.e. manufacturing, construction, communication, and transportation. With 16 questions in each area, there are 64 in total. The test was administered to 1350 seventh- and eighth graders in 13 states in the USA. The test is based on the rationale of a three-dimentional matrix for the study of technology.

Hayden (1989) tried to understand the construct of industrial technological literacy using a questionnaire. He offered his own interpretation of the definitions of technology and technological literacy. Hayden divided technological literacy into three domains:

1. Techniques—including agriculture, medicine, industry, information and the military.
2. Competence—including evaluation, synthesis, analysis, application, comprehension, and knowledge.
3. Roles—including producers, consumers and citizens.

Based on the three domains, a test on industrial technological literacy was developed. The test, which includes a total of 75 four-choice items, each with one correct answer, was administered to 8,066 high school students and 2,655 college students. The results show that:

1. Overall, high school students score lower on the test, indicating a lower level of technological literacy.
2. The level of technological literacy of a student is influenced by whether the student has taken any courses related to technology education.

Using the test on technological literacy developed by Hameed (1988), Shearrow (1992) evaluated the level of technological literacy of middle-school students in Franklin County, Ohio, USA. The independent variables under investigation included the age of the student, school budget and whether or not the student had taken industrial arts classes. The results of the study indicate that there are significant differences in terms of the levels of technological literacy between different age groups, schools with larger or smaller budgets, and those students who have and those who have not taken industrial arts classes.

In Taiwan, Hsu (1994) incorporated the nine criteria of technological literacy used in the study by Smalley & Brady (1984) into the four technological domain systems (manufacturing, construction, communication, and transportation) in her technological literacy test consisting of 45 four-choice items, each with one correct answer. The results of the study show that the levels of technological literacy among junior high school students do not exhibit significant differences in accordance with gender or grade.

In a study by Yin (1992), the computer literacy of college students in Tainan, Taiwan was investigated. The focus of the study was the content of computer literacy among college students, and the content of computer literacy a college graduate should possess. The subjects of the study included a total of 114 seniors at Cheng-kung University and Tainan Teacher's College in Tainan, Taiwan. They filled out the "Computer Literacy Questionnaire", responding to questions on what computer litercay they think they should have and actually have. The results indicate that out of the six aspects, i.e. hardware, programming, software and data, application, the influence and value of attitudes, and motivation, college students regard software and data as the key aspect of computer literacy that a college student should possess while the ability of programming is lacking in general among college students. The study also indicated that those who study in the university have far better computer literacy than those who study in the teacher's college.

In the following year, Tan (1994) conducted a comparative study on the related factors affecting computer literacy in elementary schools in the southern part of Taiwan. The main purpose of the study was to investigate the computer literacy possessed by fifth- and sixth graders in elementary schools, i.e., to determine differences in computer literacy due to gender, grade, and prior learning of computers. The subjects were a total of 397 fifth- and sixth graders in Ta-Chiao Elementray School in Tainan County and in Chih-Hsien Elementary School in Kao-hsiung City. The results show:

1. The fifth- and sixth graders performed better in terms of attitudes towards computers but not so well in terms of programming.
2. Those with prior experience of learning to use computers performed better than those without any prior experience, in terms of their ability to use computers, computer programming, and computer applications, and their attitudes towards computers. However, they scored lower in terms of their knowledge of computer hardware.
3. The sixth graders outperformed the fifth graders considerably in every aspect of computer literacy.
4. Male pupils performed better than their female counterparts in terms of their knowledge of computer hardware and their attitudes towards computers. However, the female pupils performed better in terms of their ability to use computers, computer programming, and computer applications.

From the above literature review on technological literacy, the following conclusions may be drawn:

1. Technological literacy is measurable, and it is absolutely necessary to develop an effective instrument to evaluate technological literacy. On one hand, it may be used to understand the current level of technological literacy, i.e. to make a placement evaluation, which will serve as a reference for the design and planning of technological literacy curricula. On the other hand, it may be used to understand how the students have learned, i.e. to make a summative evaluation, in order to determine whether the courses served their expected purposes.
2. In terms of the framework of technological literacy, technological literacy should cover the cognitive, affective and psychomotor domains. However, the technological literacy tests designed so far have all focused on the cognitive domain.
3. Most studies have emphasized the foundation of criteria for technological literacy.
4. There are several major ways to design question items for technological literacy tests: they may be based on technology systems, e.g. Hameed (1988); based on the definition and framework of technological literacy, e.g. Hatch (1985) and Hayden (1989); based on the criteria for technological literacy, e.g. Smalley & Brady (1984); or based on a combination, e.g. Hsu (1994).
5. Up to the present, technological literacy tests designed both domestically and abroad have mostly used four-choice items, each with only one correct answer. DeVore (1986) indicated that in order to measure effectively the level technological literacy of an individual, a combination of mutiple-choice, matching, analysis and ordering, true-false, problem-solving, simulation and game items is needed. The best approach is to design a computer program so that any individual may conduct self-assessment at any time, and to keep a record of the progress of his or her technological literacy for self-evaluation.
6. Most studies show that students in higher grades outperform those in lower grades.
7. In terms of gender differences in levels of technological literacy, there is currently no unanimous conclusion. Some studies showed that male students possessed higher levels of technological literacy than female students while others found that there was no significant difference between male and female students in terms of their levels of technological literacy.

In addition, from the literature review of previous studies, it is found that gender and grade are the main variables used in research on technological literacy. Taking into consideration the fact that research on technological literacy is relatively new in the Taiwan, and also the feasibility of data-gathering for the study and the time limitation, this study also focused on the two variables. As for other possible factors which may influence technological literacy, such as the family's

Gender & Education Level

Technological Literacy	
Ability Items of Technological Literacy	**Technology Systems**
1. Understand the definition and content of technology 2. Understand the major domains of technology 3. Understand the evolution of technology 4. Understand and predict the future trends of technological development 5. Understand the basic principles that technology is based on 6. Understnad and use effectively the tools, machines, materials, products, and operational procedures of technology systems. 7. Use technological literacy in the cognitive, affective, and psychomotor domains for problem-solving 8. Make proper judgment of technology and its products through data-gathering, analysis, and induction. 9. Understand the impacts of technology on the individual, society, culture and environment. 10. Adopt measures to adapt to changes brought on by technology	1. Construction technology 2. Manufacturing technology 3. Transportation technology 4. Communication technology 5. Energy & Power technology 6. Biotechnology

Fig. 1. The framework of research.

socio-economical background, the student's intelligence and academic performance, they are left to be explored in future studies.

IV. Research Method

The study used a questionnaire survey to explore the current state of technological literacy among junior high school and elementary school students in Taiwan. What follows is a detailed account of the framework, subjects, and instrument, used in the study.

1. The framework of the study is shown as Figure 1.
2. The subject

The subject of this study included ordinary students in public elementary and junior high schools in Taiwan. With a 5% of sampling rate, this study used stratified random and cluster sampling method to collect data from 3069 (3066 returned) students in 44 junior high school, and 3541 (3420 returned) students in 60 elementary schools.

3. The instrument

The instrument used in this study was the Survey of Technological Literacy among Junior High School and Elementary School Students, designed by the researchers. It consists of two major parts: basic information and a technological literacy test.

(1) Basic information: The basic information inquired into in this study was gender and grade.

(2) Technological literacy test:

A. Planning Stage

(a) Review relevant literature, both domestic and foreign, to define technology and its content, framework and the goals of technology education, so that ten ability items of technological literacy was developed (Fi.g 1.).

(b) Collect both domestic and foreign technological literacy tests. Based on the established ability items of technological literacy stated earlier, select items that suit junior high school and elementary school students in Taiwan.

(c) Rewrite selected items to make their descriptions more fluent and lively with additional items to be added by researchers to complete the framework of test.

(d) After the draft of the test is finished, ask scholars and experts in Taiwan to assess the content validity of the test. Discuss the relevancy of the content and the clarity of the questions in the draft. Researchers make suggestions and modify the test.

B. Pretest

In order to understand the relevancy of the question items and the answering situation of the students, a pretest was carried out in January, 1995. One or two junior high or elementary schools were selected in the northern, central, southern and eastern areas of Taiwan. In each school, a random sampling of ninth-graders and sixth graders was given the pretest. A total of 109 pretest questionnaires, 53 of which were completed by elementary school students and the rest (56) filled out by junior high school students, were completed.

C. Item analysis

After the pretest, an item analysis of the technological literacy test was conducted. The items analyzed included percentage passing, item difficulty, item-total correlation coefficient, t-test, and option ordering.

After the item analysis, the scholars and experts examined one test item after another. There was at least one item under every category, and the number of items under each ability item was made as equal to the number of items under each technology system as possible. Items of approximate difficulty and discrimination were selected and the descriptions of the items and options were modified. The difficulty of the test items selected in the study was between .3 ~ .8 while the discrimination analysis (t-value and item-total correlation) reached $P<.05$. Some items involving important concepts had higher item difficulty and therefore lower item discrimination, but they were still accepted for pretest item analysis of the test.

After modification, there were 80 items in total in the test. The first 40 items were suitable for both elementary and junior high school students; therefore, they made up the fundamental section. The last 40 were suitable for junior high school students and made up advanced section.

The reliability of the test was calculated using KR-20. After pretest, the reliability of the test in junior high schools was .91, while that in elementary school was .84. This shows the high internal consistency of the test items. From the results of the item analysis and reliability of the test, it is clear that all the test items in the study have good discrimination and consistency.

V. Findings and Conclusions

1. The analysis of technological literacy in elementary school students

A. Overview

The level of technological literacy of the elementary school students was fair, with the whole group scoring 71.77%. In terms of technological systems, they scored highest on communication technology but lowest on biotechnology. In terms of ability items, they scored highest on the item "Understand the definition and content of technology" but lowest on the items "Adopt measures to adapt to the changes brought on by technology" and "Understand and use effectively the tools, machines, materials, products, and operational procedures of technology systems".

B. By Gender

Overall, the technological literacy level of the male elementary school students was not significantly different from that of their female counterparts. Significant differences existed, however, between the male and female elementary school students in terms of technology systems and ability items; the female students performed better than the male students in most aspects. In terms of technology systems, the female elementary school students scored higher than the male elementary school students on four technology systems: manufacturing, transportation, communication and biotechnology. The male pupils scored higher on the energy and power technology. In terms of five ability items, female pupils scored higher on five ability items: "Understand the definition and content of technology", "Understand the evolution of technology", "Use technological literacy in the cognitive, affective, and psychomotor domains for problem-solving", "Make proper judgment of technology and its products through data-gathering, analysis, and induction", and "Understand the impacts of technology on the individual, society, culture and environment". The male pupils scored higher on two ability items: "Understand the major domains of technology", and "Understand and use effectively the tools, machines, materials, products, and operational procedures of technology systems".

2. The analysis of technological literacy in junior high school students

A. Overview

The level of technological literacy of the junior high school students was fair, with the whole group scoring 68.5%. In terms of technological systems, they scored highest on communication technology but lowest on biotechnology. In terms of the ability items, they scored highest on the item "Understand the definition and content of technology" but lowest on the ability item "Understand and use effectively the tools, machines, materials, products, and operational procedures of technology systems".

B. By Gender

Overall, the technological literacy level of male junior high school students was not significantly different from that of their female counterparts. Significant differences existed, however, between the male and female junior high school students in terms of technology systems and ability items. In terms of technology systems, the female junior high school students scored higher than the male junior high school students on communication technology while the male students scored higher on construction and biotechnology . In terms of ability items, the female students scored higher on three ability items: "Understand the definition and content of technology", "Understand the evolution of technology", and "Understand the impacts of technology on the individual, society, culture and environment", while male students scored higher on two ability items: "Understand the basic principle that technology is based on" and "Understand and use effectively the tools, machines, materials, products, and operational procedures of technology systems".

C. Levels of Testing

In terms of different levels of testing, the junior high school students performed well (77.36% score) on the fundamental section of the technological literacy test. But they performed poorly (59.65% score) on the advanced section. The Junior high school students scored higher than the elementary students on the fundamental section of the test. The Junior high school students on the whole, or by gender, scored better on the fundamental section than on the advanced section in terms of overall technological literacy, different technology systems and ability items. This indicates that junior high school students have higher technological literacy.

In terms of technology systems, the junior high school students scored highest on communication technology and lowest on biotechnology in both the fundamental and advanced sections. The ranking order of scores on other technology systems was not the same. Manufacturing technology ranked higher in the advanced section than in the fundamental section while communication technology ranked lower. In terms of ability items, quite a drastic change could be seen in the ranking order of scores for the fundamental and advanced sections. Rising considerably in the ranking were three ability items: "Understand the evolution of technology", "Understand and predict the future trends of technology development", and "Adopt measures to adapt to the changes brought on by technology". Dropping considerably were three ability items: "Understand the major domains of technology", "Understand the basic principles that technology is based on", and "Understand the impacts of technology on the individual, society, culture and environment", each of which had a score lower than 50%. This shows a lack of deeper understanding of basic principles of technological literacy and application knowledge among junior high school students.

D. Sources of Technological Literacy of Junior High School Students

The main sources from which the junior high school students thought they themselves obtained technological literacy were as follows: newspapers, magazines, and books (76.44%), television and radio (69.85%), and school textbooks (21.08%). Of all the school subjects, physics and chemistry, biology, earth science, industrial arts and civil education, were rated as subjects from which technological literacy could be learned most while fine arts, music, counseling, english and mathematics were rated as the subjects from which technological literacy could be learned least.

Based on the above analyses, we can draw the following conclusions:

1. Overall, the level of technological literacy of elementary- and junior high school students in Taiwan is fair. Of the six technology systems, their communication technology literacy is best while their biotechnology literacy is the worst and leaves much to be desired. Of the ten ability items, elementary students have knowledge literacy of basic technological theories, but they lack knowledge of practicability (e.g., understanding and using effectively the tools, machines, materials, products, and operational procedures of technology systems) and applicability (e.g., adopting measures to adapt to the changes brought on by technology). Junior high school students, on the other hand, lack sufficient knowledge of the fundamental principles as well as practical and applicable knowledge.

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This shows that elementary- and junior high school students may lack the ability to convert and apply the knowledge of fundamental principles and basic theories that they have learned. This is a problem worthy of attention.

2. At the elementary school level, female students have a higher level of technological literacy than male students. At the junior high school level, however, male students have a higher level of technological literacy than female students, especially in terms of the application of technological knowledge. This may indicate that male students going from elementary level to junior high school level make greater progress in technological literacy than female students; i.e., the results of technological literacy education for male students are better than those for the female students.
3. Junior high school students are better than elementary school students so far as the fundamental level technological literacy is concerned. Their fundamental level technological literacy is also better than their advanced level technological literacy. This indicates that as they become older and receive more education, their level of technological literacy also rises, but that their level of technological literacy is still quite insufficient.
4. School education is not evaluated as the primary source of technological literacy by junior high school students. This may be because the textbooks used in elementary- and junior high schools do not include all important aspects of technological literacy, or it may be because teachers do not teach enough technological literacy. This should be a focus of further research.

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國中國小學生技學素養之研究

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摘　　要

本研究之目的在瞭解目前台灣地區國中、國小學生所具有的技學素養程度，以做為未來相關課程規畫與設計之參考。研究採分層隨機叢集抽樣的方式，由台灣地區各縣市公立國中、小學中抽取國中44校，三年級學生3066人；國小60校，六年級學生3420人，以研究者自編之「國中、小學技學素養測驗」進行問卷調查，根據研究結果，歸納出下列結論：

一、台灣地區國中及國小學生技學素養程度以整體來看表現尚可，在六個科技系統中，以對傳播技學之技學素養最佳。在技學素養能力項目中，對有關技學之基礎理論認知較佳，但欠缺實用性或應用性的知識。

二、在國小階段，女學生之技學素養程度較男學生為佳，但至國中階段，則呈現男學生優於女學生的現象，尤其在對於技學知識的應用方面更是如此。

三、不同地區之國中或國小學生之技學素養程度有顯著差異。

四、國中學生具有之基本技學素養較國小學生為高，但在較進階的技學素養表現上，則略顯不足。

五、國中學生自評最主要的技學素養知識來源是報紙、雜誌、書籍、電視、或廣播。

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Science Teachers' Intentions to Teach about HIV/AIDS

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Abstract

Results of this study showed that most science teachers did intend to teach about HIV/AIDS in science classes. The theories of reasoned action and planned behavior were applied to examine and predict science teachers' intentions to teach their students about HIV/AIDS. Three variables of theories, attitude toward teaching about HIV/AIDS, subjective norms, and perceived behavior control, could explain 74% of the variance in science teachers' intentions. Attitude toward teaching about HIV/AIDS was the most significantly important factor in the prediction. Variables representing science teachers who taught biology, grades 7 and 12, and had past experiences of teaching about HIV/AIDS also made significant contributions to the prediction of teachers' intentions. Analysis of variance significantly found that respondents who intended to teach about HIV/AIDS had a higher HIV/AIDS knowledge score, more positive attitudes toward teaching about HIV/AIDS, less negative social influence mostly from principals, school board members, and parents, as well as adequate resources and material to teach about HIV/AIDS. Teachers with higher intentions were also less embarrassed to talk about sexual information and felt more comfortable dealing with the contents of HIV/AIDS education and their moral beliefs. These factors which influence teaching about HIV/AIDS should be recognized so as to encourage science teachers' participation.

Key Words: Science Teacher, Teacher's Behavior, Theory of Reasoned Action, The Theory of Planned Behavior, HIV/AIDS Education

I. Introduction

Since the first Acquired ImmunoDeficiency Syndrome (AIDS) cases were recognized in 1981, problems of AIDS and Human Immunodeficiency Virus (HIV) Infections have caused untold disruptions to the world. Recently, adolescents have been identified as one group that is at high risk for AIDS and HIV infection (Diclemente, 1990; Hein, 1989). Although few young adolescents, age 13-19, are diagnosed as having AIDS, AIDS cases have been reported to be increasing dramatically in young adults, age 20-29 (CDC, 1993). Because of the long latency period of the disease, this evidence indicates that many of these young adolescents were infected with HIV in their teenage years. AIDS plays a significant role in the increased morality rate of the younger generation. Former U.S. Surgeon General C. Everett Koop, and such prestigious organizations as the Institute of Medicine and the National Academy of Science, have concluded that preventive educational programs are the best defense against the spread of HIV/AIDS in the absence of a vaccine or medical cure. Schools must play a role in the effort to control or eventually stop this disease (Futrell, 1988). Schools serve millions of students everyday, and school-based HIV/AIDS programs may also be the only formal instruction which citizens will receive on this critical health problem in their lives. Although many schools are providing HIV/AIDS education at some level, this does not guarantee that students in schools can receive information about HIV/AIDS (Haffner, 1992, CDC, 1990). Most teachers do not intend to teach about HIV/AIDS because this topic deals with sensitive issues related to sexuality and morality (Burak, 1992; Fetter, 1989).

In the early stages of informing students about HIV/AIDS, CDC identified health education as the primary source of HIV/AIDS education. With the explosion in the number of new AIDS cases, limiting exposure to one health class is not sufficient to prepare youth to face the problem of HIV/AIDS. Life science and biology teachers are particularly in a key position to accomplish this task (Speece, 1992; Vener & Krupka, 1988, 1990). Science teachers usually have a deeper understanding of the immune system and the nature of viruses, which serve as a starting point for HIV/AIDS education (Speece, 1992). As the former Surgeon General has called for HIV/AIDS education to begin in the early elementary grades (Koop, 1986), life science and general science teachers are the most appropriate persons to provide an effective HIV/AIDS program for all students. HIV/AIDS education presents a great challenge to science teachers in all grades (K-12). This study attempted to predict and examine science teachers' intentions to teach about HIV/AIDS and to recognize numerous factors which may influence science teachers' decisions to teach or not to teach about HIV/AIDS.

Decision making has been recognized to play an important role in the reform of education. Science teachers in Taiwan are getting more and more opportunities of making decisions in their classes. The focus of this study is to exam and understand science teachers' characteristics and factors which influence their decision making. Although data of this study were collected in Iowa, the U.S., results of this study still can provide information and suggestions for encouraging science teachers to be engaged in some effective educational programs.

II. Rationales

1. The Theory of Reasoned Action

Teaching is a human social behavior. Teachers' decision making has been shown to be a result of intra- and inter-personal processes, thus it seems appropriate to use a behavioral theory to examine this behavior. The theory of reasoned action (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975) uses a single framework to predict and understand all human behaviors. The theory rests on the assumptions that humans are rational, have control over their behavior, and seek out, utilize, and process all available information about pending decisions before they take actions (Crawley & Koballa, 1994). According to the theory of reasoned action, a person's intentions to engage in a behavior are a function of her/his attitudes toward that behavior and her/his subjective norms regarding the behavior. An equation for predicting intentions is offered (Fishbein & Ajzen, 1975):

$$B\sim I=wl[AB]+w2[SN]$$

In this equation B~I is the intention to perform the behavior, AB is the attitude towards the behavior, SN is the subjective norms and wl and w2 are the respective weights associated with the attitude and subjective norms. This model provides for the weighting of attitudinal and normative components in order to reflect their relative importance in determining behavioral intentions.

Attitude towards the behavior is the personal component that indicates an individuat's feelings about performing or not performing the behavior. It is a function of the expected outcomes of behavioral beliefs and the evaluations of these expected outcomes. Thus, the belief-based attitude score ($BA=\Sigma$ biei) can be measured by the sum of the products of the outcome beliefs (bi) and their evaluations (ei). The subjective norm is the person's perception of the social pressures to perform or not perform the behavior. It is a function of normative beliefs regarding the performance of the behavior and the motivation to comply with these normative beliefs. Thus, the belief-based subjective norm score ($BSN=\Sigma$ nbmc) was derived by summing the products of the normative beliefs (nb) and motivations to comply (mc).

The theory of reasoned action recognized three kinds of variables that function as the prime determinants of behavioral intention: attitude toward the behavior, subjective norms, and the weights of these predictors. In turn, the determinants of attitude toward the behavior are beliefs about the behavior and the expected outcomes of acting on these beliefs. The determinants of subjective norm are beliefs about the perceptions of others regarding the performance of the behavior and the motivation to comply with these beliefs. While these variables are viewed as determinants of attitude toward the behavior and subjective norm, they need not be identified in order to measure attitude toward the behavior and subjective norm and to predict behavioral intention.

A conceptual framework presents that the intention to perform the behavior is directly determined by attitudes and subjective norms, which are respectively determined by behavioral beliefs and outcome evaluation, and normative beliefs and motivation to comply. This model can be used to predict intention at any level of specificity from information on personal and normative components, provided there is correspondence between the level of specificity of predictors and criterion variables.

2. The Theory of Planned Behavior

The theory of planned behavior was proposed by Ajzen (1985) as an extension of the theory of reasoned action to account for the performance of behaviors which are not completely under the subject's control. Ajzen (1985) addressed the factors which include possession of the requisite information, skills and abilities to carry out the behavior, a person's perceptions, will power, emotions, compulsions, the time, opportunity, resources and cooperation from others can influence or interfere with the intended performance of the behavior. These factors contribute a third construct to the model, perceived behavioral control (PBC), which has a direct impact on the formation of behavioral intention and it is independent of the contributions of attitude and subjective norm (Ajzen, 1985, 1988, 1989; Ajzen & Madden, 1986). The model variables comprising the theory of planned behavior are summarized in the following equation:

$$B \sim I = w1[AB] + w2[SN] + w3[PBC]$$

The belief-based perceived behavioral control (BPBC) score can be measured by summing salient belief scores which indicate influences of control over intended performance.

III. Methods

A self-administrated questionnaire was used to measure science teachers' intentions to teach about HIV/AIDS. The theory of reasoned action and the theory of planned behavior were applied to predict science teachers' willingness to participate in HIV/AIDS education. The relationships between the intentions, attitudes, subjective norms, and perceived behavioral control related to teaching about HIV/AIDS samples were examined in this study.

1. Subjects

A total of 697 science teachers from 5th grade to 12th grade participated in this study. These science teachers were selected through a stratified systematic sampling procedure to represent the overall science teachers population in Iowa. Participants were selected from the different sized public school district groups and one private school district group which was religion oriented. Information about science teachers was provided by the Iowa State Department of Education in Des Moines. Of the 697 questionnaires distributed to science teachers, 288 were returned, giving an overall response rate of 41.32%. Ten of the questionnaires which were not completely finished were unusable, resulting in a net response rate of 39.89% (n=278).

2. Instrumentation

Questions used to predict intentions of science teachers to teach about HIV/AIDS were constructed in two phases according to the guidelines for the construction of a standard theory of reasoned action questionnaire (Ajzen & Fishbein, 1980). In the first phase, the target behavior, teaching about HIV/AIDS in science class, was clearly identified. Three questions; "What are the most likely positive or negative outcomes of teaching about HIV/AIDS in your class?", "Who are important people or groups that might influence your teaching about HIV/AIDS?", and "What are factors that might facilitate or hinder your teaching about HIV/AIDS?" were designed to elicit science teachers' outcome beliefs, normative beliefs of referents, and beliefs referring to control factors related to the target behavior. Twelve former and experienced science teachers were asked to identify their beliefs related to the target behavior in these questions. Beliefs which were identified by 75% of these experienced science teachers were selected to be modal salient beliefs (recommended by Ajzen & Fishbein, 1980). Six outcome beliefs, eight referent individuals or groups, and six factors which might influence control over teaching about HIV/AIDS were identified from the belief elicitation survey. These salient beliefs were content analyzed, similar items were combined, and the resulting information was used to formulate the questionnaire items in the second phase.

In the final instrument, the focus of the dependent variable was intention to teach about HIV/AIDS in science class. Respondents were asked to indicate their level of agreement with the statements that they would try to teach about HIV/AIDS in class. Intentions are determined by attitudes, subjective norms (Fishbein & Ajzen, 1975; Ajzen & Fishbein, 1980), and perceived behavioral control (Ajzen, 1985, 1988; Ajzen & Madden, 1986). Thus, attitude, subjective norm and perceived behavioral control were the main independent variables in this study. All these measures were scored on seven-point scales. The face validity of the questionnaire was assessed by experts in health professions and health educators. The Cronbach Coefficient Alpha (0.71-0.90) for each measure was calculated to assess the reliability.

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Table 1. Means Scores for Variables of the Theories of Reasoned Action and Planned Behavior

Variable	Mean	Range	SD
Intention	11.18	2-14	3.26
Attitude (Teaching)	5.82	1-7	1.60
Subjective Norm	2.10	1-7	1.52
Perceived Behavioral Control	5.74	1-7	1.76
Belief-Based Attitude	225.54	19-294	51.12
Belief-Based Subjective Norm	89.10	8-288	50.88
Belief-Based Perceived Behavior Control	28.48	11-42	6.84

Table 2. Correlation Matrix of Variables of Theories of Reasoned Action and Planned Behavior Control

	Int.	Att.	SN	PBC	B.Att	B.SN	B.P
Int.	1.00						
Att.	0.85	1.00					
SN	-0.46	-0.45	1.00				
PBC	0.27	0.20	-0.25	1.00			
B.Att	0.48	0.52	-0.38	0.07	1.00		
B. SN	-0.47	-0.43	0.63	-0.18	-0.43	1.00	
B. P	0.59	0.53	-0.41	0.16	0.50	-0.45	1.00

Int. = Intention to Teach About HIV/AIDS
Att. = Attitude toward Teaching About HIV/AIDS
SN = Subjective Norm
PBC = Perceived Behavioral Control
B.Att = Belief-Based Attitudes
B.SN = Belief-Based Subjective Norm
B.P = Belief-Based Perceived Behavioral Control

3. Data Analysis

Mean scores of variable of the theory of reasoned action and the theory of planned behavior were calculated. Relationships among the major variables (intention, attitude toward teaching about HIV/AIDS, subjective norm, perceived behavioral control, belief-based attitude, belief-based subjective norm, and belief-based perceived behavioral control) were described by correlation coefficients. Multiple regression analyses were carried out to predict science teachers' intention to teach about HIV/AIDS. Regression coefficients were obtained to indicate the relative importance of the variables in predicting intention to teach about HIV/AIDS. Variables (sex and moral issues) and characteristics of subjects (gender, age, teaching experience, type of school, prior teaching about HIV/AIDS, and receiving in-service training) which were considered external to the theories of reasoned action and planned behavior were added into the regression equations in order to determine their contributions to variances in intentions.

The intention score, scores of attitude, subjective norm and perceived behavioral control regarding teaching about HIV/AIDS and belief-based scores of attitude, subjective norm, and perceived behavioral control were examined via one way analyses of variance. Post hoc Tukey tests were used to examine differences between comparison groups. Data were analyzed using the SAS system, version 6.08.

IV. Results

The purpose of this study was to examine and predict science teachers' intentions to teach about HIV/AIDS. The total number of respondents was 278 out of 697 polled. Respondents included 88 females and 190 males representing all levels of middle, junior high, and senior high school science teachers, from grade 5 through grade 12. Most of the science teachers were 40-50 years old (44.6%), and 66 percent reported that they had more than 10 years teaching experience. The popular media from which the respondents got HIV/AIDS information included television (45%), newspapers (48.6%), health professionals (43.9%), health organizations (43.9%), and professional journals (42.1%).

1. Intention; Attitude Toward Teaching About HIV/AIDS, Subjective Norms and Perceived Behavioral Control

The mean intention score was 11.18 of 14 points on the scale (Table 1), which indicated that Iowa science teachers have high inclination to teach about HIV/AIDS in their science classes. The mean attitude toward teaching about HIV/AIDS score of 5.82 showed that Iowa science teachers generally have positive attitudes toward teaching about HIV/AIDS in their classes. The low mean subjective norm score of 2.10 suggested that the social influence was positive for respondents to teach their students about HIV/AIDS. Perceived behavioral control is a concept that extends the theory of reasoned action into the theory of planned behavior. Perceived behavioral control refers to an individual's conceptions regarding the difficulty or ease of performing a given behavior. The mean perceived behavioral control score of 5.74 indicated that Iowa science teachers think they do have control over teaching or not teaching their students about HIV/AIDS.

Pearson correlation coefficients were calculated for the measures of the major variables and their

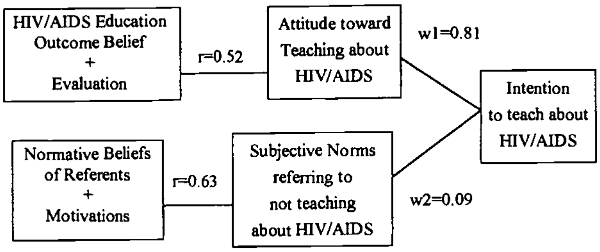

Fig. 1. Graphic representation of the theory of reasoned action analysis.

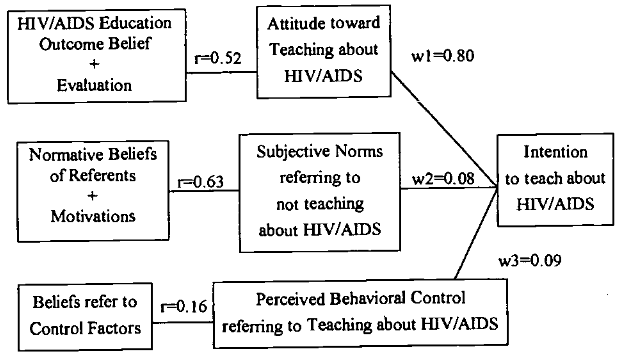

Fig. 2. Graphic representation of the theory of planned behavior analysis.

belief-based measures (Table 2). The correlation between the attitude measure and belief-based attitude measure was 0.52. The correlation between the subjective norm measure and belief-based subjective norm measure was 0.63. The correlation between the perceived behavioral control and belief-based perceived behavioral control was 0.16.

2. Prediction of Intention to Teach About HIV/AIDS

Multiple regression analysis was first conducted using variables of the theory of reasoned action. Intention to teach about HIV/AIDS was first regressed on attitude and subjective norm according to the reasoned action theory. A multiple R of 0.85, an R^2 of 0.73, and an adjusted R^2 of 0.73 (F=30.72, df=2,275, p=0.0001) were obtained in this model. Attitude and subjective norm accounted for 73% of the variance in science teachers' intentions. Figure 1 shows a graphic representation of the analysis based on the theory of reasoned action. When the additional variable of planned behavior theory, perceived behavioral control, was added into the multiple regression analysis, the multiple R increased to 0.86, the R^2 to 0.74 and the adjusted R^2 to 0.73 (F=225.94, df=3,274, p=0.0001). Variables of the theory of planned behavior (attitude, subjective norm, and perceived behavioral control) accounted for 74% of the variance in science teachers' intention to teach about HIV/AIDS in science classes. Figure 2 is a graphic representation of the theory of planned behavior analysis.

The variable attitude toward teaching about HIV/AIDS had the largest standardized regression coefficient in all these models (0.81 in the model of reasoned action theory, 0.80 in the model of planned behavior theory, and 0.71 in the model of four variables to predict intentions). This indicated that attitude toward teaching about HIV/AIDS is a significantly important factor in prediction of science teachers' intentions.

3. External Variables

Characteristics of subjects, the HIV/AIDS knowledge score, sex issue, and moral issue were considered to be external variables according to the theories of reasoned action and planned behavior. These variables influence beliefs and the formation of attitude, subjective norm and perceived behavioral control. In subsequent multiple regression analyses, four external variables were found to contribute significant variance in intention. The variable representing that science teachers taught about HIV/AIDS in the past made a significant contribution to the variance in intention. When the past experience of teaching about HIV/AIDS was entered into the analysis, R^2 significantly increased to 0.79 (F=207.10, df=5,272, p=0.0001). This variable contributed an additional 3% to the variance in intention. Grade 12 and grade 7, which science teachers taught, were the other two variables which increased R^2 when they were added to the analysis. Grade 12 increased R^2 to 0.77 and made an additional 1% contribution to the variance in intention. Grade 7 increased R^2 to 0.764 and contributed an additional 0.1% to the variance in intention. The teaching subject Biology was also found to contribute an additional 1% to the variance in intention to teach about HIV/AIDS. Science teachers who taught Biology were more likely to intend to teach their students about HIV/AIDS. This variable increased R^2 to 0.77 (F=185.68, df=5,272, p=0.0001).

4. Different Intention Groups

All the subjects were divided into three groups based on their intention scores. The three categories were science teachers with high intention (scores>10), neutral intention (6<scores≤10), and low intention

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Table 3. Mean Scores of Three Different Intention Groups

Measure	Intention				
	High	Neutral	Low	F-Value	p
Intention	13.30	8.75	4.17		
Attitude toward Teaching About HIV/AIDS	6.71[a]	4.82[b]	2.86[c]	261.37	0.0001
Subjective Norms	1.67[C]	2.59[b]	3.52[a]	28.17	0.0001
Perceived Behavioral Control	6.03[a]	5.42[b]	4.72b	8.82	0.0002
Belief-Based Attitude toward Teaching about HIV/AIDS	241.51[a]	204.97[b]	177.90[c]	33.33	0.0001
Belief-Based Subjective Norms	73.22[c]	109.79[b]	135.83[a]	32.93	0.0001
Belief-Based Perceived Behavioral Control	31.43[a]	23.89[b]	21.62[b]	70.89	0.0001

Note: the mean scores with the same letters are not significantly different (α=0.05)

(scores≤6). This division resulted in 178 science teachers with high intentions, 71 science teachers with neutral intentions, and 29 science teachers with low intentions to teach about HIV/AIDS. Differences of measures among these three groups are presented in Table 3. For measures of attitude toward teaching about HIV/AIDS, subjective norms, belief-based attitudes, belief-based subjective norms, and the feeling about moral issue. The Post hoc Tukey test was used to calculate the significance (0.05) of differences between high and neutral, neutral and low, and high and low intention groups. For the perceived behavioral control score, belief-based perceived behavioral control score, sex issue score and the HIV/AIDS knowledge score, significant differences were found between high vs. low and high vs. neutral intention groups. All these analyses were significant at 0.05.

In summary, Iowa science teachers who intend to teach their students about HIV/AIDS have significantly more positive attitudes towards teaching about HIV/AIDS than do the groups with neutral or low intentions. Science teachers with higher intentions believed that other people do not think that they should not teach about HIV/AIDS, and that they have more control over their teaching about HIV/AIDS. Compared to the other two intention groups, less negative attitudes toward sex and moral issues were found in the high intention group. The HIV/AIDS knowledge scores were also different, and science teachers in the high intention group had more accurate knowledge about HIV/AIDS.

V. Discussion

Although the results of this study provide empirical support for the theory of reasoned action and the theory of planned behavior, the addition of perceived behavior control resulted in a nonsignificant increase (1%) in variance. These results indicate that the theory of reasoned action might be sufficient to account for variance in science teachers' intentions. Teaching about HIV/AIDS appeared to be totally under the control of these science teachers because of the teaching subjects and opportunities available to these respondents. The findings of this study are similar to the results of Crawley's study (1990), which used the planned behavior theory to examine science teachers' intentions to use teaching methods learned in in-service courses. These findings were also consistent with Ajzen's (1988) caution that when control is maximum and behavior is voluntary, the theory of planned behavior can be reduced to the theory of reasoned action.

The major variables of theories are based on beliefs regarding the possible outcomes of the behavior, the normative beliefs of specific referents, and beliefs about factors which could facilitate performance of the behavior, so measures of major variables and their belief-based measures should be moderately correlated. In this study, it was found that the perceived behavior control had a quite low correlation with its belief-based measure (r=0.16). But the belief-based behavioral control was correlated with the intention to teach about HIV/AIDS (r=0.59) and with attitude toward teaching about HIV/AIDS (r=0.53), suggesting that factors which facilitate performance of a behavior, like requisite knowledge, skills, availability of adequate materials and curriculum, did influence these science teachers' intentions.

In this study, attitude toward teaching about HIV/AIDS had the highest standardized regression coefficient and the highest correlation coefficient with the behavioral intention. This indicated that teaching attitude had the greatest influence on these science teachers' intentions to teach about HIV/AIDS. Most of the science teachers did believe that teaching about HIV/AIDS in the science class can provide students with accurate scientific information about HIV/AIDS (product score=42.91) and can help students develop preventative health behaviors (product score=39.19). Social influence could have effects on the behavior of teaching about HIV/AIDS. In this study, most of the negative influence resulted from the school/building principal, the school board members, and parents of students. Results suggested that the roles of the school/building principal, school board members, and students' parents are quite powerful with regard to implementation of HIV/AIDS education by science teachers.

The subject which a respondent taught was also a factor influencing the intention to teach about HIV/AIDS. Since the virus and the disease are closely related to biological science, science teachers who taught biology had high intentions to teach this topic and could easily add HIV/AIDS information to their curricula. Results of this study suggest that biology teachers are the best candidates to participate in HIV/AIDS education. Science teachers who taught grade 7 and grade 12 were identified to be more comfortable with teaching about HIV/AIDS. Seventh grade students are sufficiently cognitively developed to receive information about the disease and sex. Students in grade 12 are ready for more advanced scientific knowledge about HIV/AIDS. Thus, students in grade 7 and grade 12 could be the best candidates to receive appropriate materials about HIV/AIDS. The other important factor facilitating science teachers' intentions was the past experience of teaching about HIV/AIDS. Past experience of teaching about HIV/AIDS might be helpful for science teachers to organize a proper curriculum, manage some embarrassing questions, and prepare themselves for discussing HIV/AIDS with their students.

Results of this study showed that science teachers who did NOT intend to teach about HIV/AIDS had more negative teaching attitudes, social influence and less perceived behavioral control. Negative teaching outcomes like leading students to early experimentation with risky behaviors and exposing students to unnecessary sexual information could reduce science teachers' intentions to teach about HIV/AIDS. Pressures from principals, school board members, and parents might make science teachers hesitate to teach about HIV/AIDS. Feelings of no control over teaching about HIV/AIDS might result in no requisite knowledge and skills as may unavailability of materials, resources and curricula. Compared to the high intention group, science teachers who had neutral and low intentions to teach about HIV/AIDS were less knowledgeable about HIV/AIDS information. They also felt embarrassed talking about sexual information and behavior and thought that teaching about HIV/AIDS could betray their moral beliefs.

According to theories, attitude towards teaching about HIV/AIDS, subjective norms, and perceived behavioral control might obstruct the performance of an intended behavior. But intentions can only predict a person's attempt to perform a behavior, not the actual performance of a behavior (Ajzen, 1985). Although results of this study showed that the science teachers highly intended to teach about HIV/AIDS, and that 71.6% of these science teachers reported teaching about HIV/AIDS in the past, more observations of HIV/AIDS teaching behaviors should be done in a future study. This study focused on factors which influence science teachers' intentions to teach about HIV/AIDS. Understanding these factors is the first step in changing negative intentions and encouraging science teachers to participate in HIV/AIDS education. If HIV/AIDS education is to become more widespread, attempts to modify intentions and increase the probability of teaching about HIV/AIDS should be made.

VI. Conclusions

The major findings of the study include these listed below.

(a) Most of the science teachers participating in this study did intend to teach about HIV/AIDS in their classes. The mean score of intention was 11.8 on a 14 point scale. Reported teaching about HIV/AIDS in the past was high (71.6% of the respondents); however, few of the science teachers (16.2%) were required by their administrators to teach this topic.

(b) The theories of reasoned action and planned behavior did provide a framework for the prediction of science teachers' intention to teach their students about HIV/AIDS. Although the theory of planned behavior did not account for more variance in teachers' intentions than the theory of reasoned action, both models could be accepted in their predictive abilities at significant level (α=0.05). Science teachers who had more positive teaching attitudes, who had more social pressure, and who perceived that they had more control over teaching about HIV/AIDS were more likely to teach their students about HIV/AIDS. The variable attitude toward teaching about HIV/AIDS had the largest standardized regression coefficient in both theory models, signifying the importance of this factor in the prediction of science teachers' intentions.

(c) External variables which are mediated by the major variables of the theories were found to make significant contributions to the prediction of science teachers' intentions. Variables representing science teachers who had past experience of teaching about HIV/AIDS, who taught grades 7 and 12, and who taught biology contributed significantly to the variance in intention.

(d) Significant differences in attitude toward teaching about HIV/AIDS, subjective norms, perceived behavioral control, three belief-based measures, the sex issue, the moral issue and HIV/AIDS knowledge score were found between those science teachers who intended to teach about HIV/AIDS, those who did not intend to teach about HIV/AIDS, and those who were neutral in regards to teaching about HIV/AIDS. Science teachers who had higher willingness to participate in HIV/AIDS education possessed higher HIV/AIDS knowledge scores, more positive teaching attitudes and better perceived behavioral controls, and they experienced less negative influence from social pressures, and they had less negative attitudes toward social and moral issues.

VII. Implications for Teaching about HIV/AIDS in Science Classes

Teaching about HIV/AIDS could be a five minute presentation or an hour lecture without telling students what the HIV virus is. Understanding how science teachers teach their students about HIV/AIDS and observations of teaching behaviors of science teachers are important in making HIV/AIDS education effective in practice. The contents of HIV/AIDS education should not be limited to abstinence or using condoms. Examinations of different HIV/AIDS curricula could provide additional information for the preparation of a proper curriculum for science classes for adolescents. HIV/AIDS curricula vary a lot in many ways. Some of them may only focus on abstinence or telling students how to use condoms. It is a big challenge for science teachers to combine these preventative messages and scientific information about the virus/ disease in an HIV/AIDS educational unit. Development of an effective and proper HIV/AIDS unit in the science curriculum needs to be studied in the future.

An effective HIV/AIDS program should have not only good materials and resources, but also good teaching strategies, which are important to make the curriculum more meaningful for students. Science, Technology, Society (STS), problem solving, peer curriculum, and analogous examples are all good strategies for teaching students about HIV/AIDS in the science class. A further study should focus on the effectiveness of these teaching strategies. It is also urgent and necessary to make HIV/AIDS in-service training programs available to all science teachers (only 38.3% of the science teachers reported receiving in-service training programs). These in-service training programs should not only provide resources and materials and be age-appropriate, but also should involve support from the larger community to prepare teachers for educating our adolescents. It is important for teachers to get support from principals, school board members, fellow teachers and parents. The training program should offer teachers information about how to get these people involved. School principals and committees should also make a commitment to participate in and support HIV/AIDS education and training programs. Parents should recognize the importance of HIV/AIDS education and cooperate with school teachers.

Education is currently the only means of preventing the spread of HIV/AIDS. The education which is needed to protect adolescents from the virus and subsequent diseases involves changes at many levels. Individuals and systems have to make changes in their thinking, behavior, attitudes, beliefs, and policies. Science classes in schools provide an opportunity to make some changes. The future of children and adolescents may well depend on effective HIV/AIDS curricula which can help them develop health related beliefs and behaviors that can prevent transmission of the HIV virus.

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科學教師對於愛滋病與愛滋病病毒的教學意願以及其相關因素之研究

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摘　要

本研究利用 Reasoned Action 和 Planned Behavior 二種理論來檢視美國 愛荷華州的科學教師教導學生愛滋病與愛滋病病毒的意願以及探討影響其教學意願的主要因素。研究結果發現科學教師有高意願來參與愛滋病與愛滋病病毒的教學行列；而教學態度、社會影響與行為難易度三個理論因素則可預測科學教師對於愛滋病與愛滋病病毒的教學意願，其中並以教學態度的影響力最大。當科學教師覺得教學的需要性與重要性愈大時，其教學意願也就愈高，而學校委員會、校長與家長對於科學教師的教學意願也有相當程度的影響。當科學教師有足夠的專業知識與教學資源，以及不被性或道德問題困擾時，亦有較高的愛滋病教學意願。除了理論因素之外，研究中亦發現教生物科、7與 12 年級以及有愛滋病教學經驗的科學教師也有較高之意願參與愛滋病教學。藉由這些研究結果，希望能鼓勵更多的科學教師參與愛滋病與愛滋病病毒的教學，並且能在科學教師的培訓與愛滋病的防治工作上有所助益。

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Enhancing College Students' Attitudes toward Science through the History of Science

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Abstract

This study explored the effect of teaching college chemistry with the history of science on student attitudes toward science. Sixty-one non-chemistry major freshmen in two classes participated in this study. Using a quasi-experimental design, the experimental group of students were taught three historical cases of chemistry in one school year. At the end of the school year, the action research reaped fruitful outcomes. The quantitative data with Analysis of Covariance, using post-treatment attitude score as the dependent variable and pre-treatment attitude score as the covariate, reveals that the experimental group (taught the history of chemistry) outperformed its counterpart in their attitudes toward science. Qualitative interview data provide additional evidence of this teaching strategy's effect.

Key Words: science history, attitudes toward science, science teaching

I. Introduction

Student attitudes toward science have long been regarded as one of the most important outcomes of science teaching. The report for Project 2061 (AAAS, 1989) pointed out that science education should help students to become compassionate human beings; the National Science Teachers Association (NSTA, 1982) also officially announced that the goal of science education is to develop scientifically literate individuals who understand how science, technology, and society influence one another. Such individuals both appreciate the value of science and technology in society and understand their limitations.

The possible relationship between attitudes toward science and course participation (or career selection) has been investigated in many studies (Fox, 1977; Greenfield, 1996; Taber, 1992). Recently, Koballa (1988) confirmed the existence of the attitude-behavior link. In addition, it was found that students' attitudes toward science are highly related to their achievement in science (Lin, 1992; Simpson & Oliver, 1990). Knowing the importance of student attitudes toward science, the National Assessment of Educational Progress (NAEP, 1978; 1983) has periodically diagnosed how American students performed in this field. Unfortunately, based on the reports of NAEP (1978), students at ages 9, 13, and 17 all declined generally in knowledge, skills, and understanding of science as determined in the 1970, 1973 assessments to 1978 assessments.

Extensive research conducted to investigate students' attitudes toward science has attracted science teachers' and educators' attention. Efforts to improve science teaching in order to promote students' interest have been made in the science education community. For instance, in Canada, an attempt to reform science education was made and various approaches to science curriculum development and science education was advocated in the 1980s. However, Ebenezer and Zoller (1993) found that no change in students' attitudes toward science could be detected. The two researchers suggested that alternative strategies should be considered and developed.

Recently, Matthews (1994) noted the importance of integrating the history of science into science teaching. He further listed several potential benefits of this teaching approach: it promotes better comprehension of scientific concepts; it connects the development of individual thinking with the development of scientific ideas; it enhances understanding of the nature of science. Although Matthews (1994) did not explicitly

97

point out the potential benefit of promoting student attitudes toward science, he mentioned that "History... humanizes the subject matter of science, making it less abstract and more engaging for students" (p. 50) and "There is evidence that this makes science and engineering programs more attractive to many students" (p. 7). In fact, the potential benefits described by Matthews (1994) have been confirmed by some researchers. For example, as early as 1963, Klopfer and Cooley successfully demonstrated the approach's effect of promoting high school students' understanding of science and scientists. More recently, Solomon, Duveen, Scot, and McCarthy (1992) conducted an action research and found that students improved in their understanding of the nature of science after they were taught with the history of science. Jensen and Finley (1995) reported that a historically rich teaching intervention effectively promoted students' conceptual change in biology. Lin (1998a) also concluded that integrating history in science teaching could facilitate student conceptual understanding of chemistry. In addition, the inclusion of history in pre-service teacher education programs has created fruitful results on students' understanding about the nature of science (Lin, 1998b).

From the above literature review, it can be seen that, to date, little research has focused on examining the potential of positive effect of teaching the history of science on student attitudes toward science, especially at the college level. It is believed that with the addition of empirical evidence, more science teachers and educators will pay attention to this teaching approach. Therefore, the purpose of this study was to investigate the efficacy of using historically rich supplemental material in teaching freshman chemistry.

II. Methodology

1. Instrument

A revised version of the Wareing Attitude toward Science Protocol (WASP) (Wareing, 1982) was used to assess students' attitudes toward science. The original 50 items of the protocol were translated into Chinese and validated by Lin (1992) with reliability of 0.91 and satisfactory validity. The Chinese version of WASP is comprised of 44 items. After each item's statement, there is a Likert-scale format with 1=strongly disagree, 2=disagree, 3=undecided, 4=agree, and 5=strongly agree. The numbers stand for each item's score. However, items with negative statement (e.g., science discourages curiosity) were scored in the reverse order. Therefore, a high total score indicates a positive attitude. The highest possible total for this questionnaire is 220.

2. Treatment

Three cases from the history of chemistry were used as the treatment in this study. All historical statements used in these cases were derived from the article of Gorin (1994) and the following four books: 1. *The Norton History of Chemistry* (Brock, 1992), 2. *The General History of Chemistry* (Chao, 1992), *Harvard Case of Histories in Experimental Science* (Conant, 1957), *The Development of Chemical Principles* (Langford, 1969).

The first case introduced how Boyle used a J tube to confirm the compressibility of air and the pressure of air in the seventeenth century. Although Boyle's method of measuring volume was crude, he obviously became very interested in the numerical relation between pressure and volume of the air inside the short leg of the J tube. Boyle supported Torricelli's idea of atmospheric pressure while most scientists at that time believed in the doctrine of "horror vacui". For example, when Torricelli explained that in his experiment, the mercury in a tube did not fall because the earth is surrounded by a sea of air that exerts pressure, Thomases asked why the mercury did not fall if the barometer was placed inside a large glass vessel that was sealed off from the surrounding air. In order to provide evidence that the pressure inside the enclosing vessel was the same as the atmospheric pressure when the vessel was first closed off, Boyle used a pump to remove the air from the vessel and successfully showed that the mercury fell. Though Torricelli and Boyle consistently confirmed the property of air, objections arose. For example, Linus hypothesized that the space above the mercury column in a Torricellian tube contained an invisible membrane. In support of his hypothesis, Linus reported that if the upper end of the Torricellian tube was closed with a finger, one could feel the flesh being pulled in. Linus further hypothesized that the membrane could draw the mercury up to a maximum height of 29 inches. However, Boyle knew that the pressure of the outside air pushed the flesh of one's finger into the top of a barometric tube. He used a J tube and an air pump to pull up a column of mercury which is several times of 29 inches. This experiment enabled Boyle to reject Linus' postulation.

The second case described how the phlogiston theory was overthrown and the existence of oxygen was proven. In the eighteenth century, the phlogiston theory was almost universally accepted by scientists.

It hypothesized that a substance called phlogiston existed in combustible substances, such as charcoal. When charcoal was burned with a metallic ore to produce a metal, according to the phlogiston theory, phlogiston escaped from charcoal in the process and combined with air. The fact that combustion soon ceased in an enclosed space was taken as evidence that air had the capacity to absorb only a finite amount of phlogiston. However, when sulfur was burned, Lavoisier found that it gained weight instead of loosing weight. This quantitative observation created great difficulties for those who believed in the phlogiston theory. Lavoisier suspected that "something" was taken up from the atmosphere in combustion. This was exactly opposite to the phlogiston doctrine. He continued to conduct experiments in decomposing the red oxide of mercury (HgO) to collect gas from a reflective furnace. After examining the properties of the gas, Lavoisier finally showed clearly that air is a mixture of two gases, one "highly respirable", the other "unable to support combustion".

The third case explained the development of atomic theory, the atomic weight table, the formula of water, and Avogadro's molecular hypothesis. Based on this historical development, students were able to learn that any element can be used as a reference, and that its atomic weight can be assigned any numerical value. For example, Dalton used hydrogen=1; Berzelius defined oxygen=100; and Cannizzaro introduced carbon=12 by calculating its relative atomic weight to the lightest atom of hydrogen, which was assigned as 1 again; after knowing that most elements are mixtures of isotopes, chemists in the International Unions of Pure and Applied Chemistry agreed to change the reference substance to carbon-12. In the description of Avogadro's molecular hypothesis, students were introduced to the scientific debate over the distinction between the concept of the atom and that of the molecule. The history of how Avogadro's molecular hypothesis was accepted by the scientists at that time was also described in this case. Although Avogadro created this hypothesis in 1814, it was not accepted until the 1860's Karlsruhe conference, which was four years after he died. One of the major reasons why it takes so long time described by historians is that Avogadro's hypothesis was not supported by Dalton, who was one of the major leaders in science community at that time. It was believed that students could develop a better understanding of these concepts from these historical descriptions. They were provided with opportunities to learn how a scientific theory is accepted by scientists, to learn that earlier scientists held misconceptions, and to appreciate the creative nature of science.

3. Procedure

Two classes of non-chemistry major freshmen (who were from the Department of Industrial Technological Education, N=61) participated in this study. One class was taught by the investigator, who is interested in history of science and very curious about its effectiveness in science teaching. The other class was taught by an experienced chemistry professor, who is not only much more experienced than the investigator in teaching, but has been recommended as a teaching performance evaluator and a reviewer of science fairs for more than 10 years. The students all used the same textbook (Snyder, 1995), in which attempts were made by the author to relate chemistry concepts to daily lives, and to enable students to make reasoned judgments on societal issues.

At the beginning of the school year, all the students were asked to respond to the revised version of WASP. The three history of chemistry cases were used as supplemental materials and taught to the experimental group. The other class taught by the experienced professor was used as the control group and was taught using only the textbook without the history of chemistry. All the students met for two hours a week in class. After one year of teaching, all the students responded to the questionnaire again. During the year, semi-structured interviews were conducted to assess the experimental group students' understanding and perceptions of the history of chemistry.

4. Data Analysis

Both quantitative and qualitative methods of data analysis were conducted. In the quantitative part, Analysis of Covariance (ANCOVA) was used to check whether there was a significant difference in student attitudes toward science between the two groups. In addition, dependent t-tests were employed to examine the two groups' progress in terms of pre- and post-test differences. All the statistical analysis was carried out using the SAS program on a VAX computer. Interview results are transcribed, abstracted, and briefly presented in the following "Results" section. Although the study appeared to employ a quasi-experimental design, the main intention was not to compare the differences of student attitudes toward science between the experimental and the control group. Instead, an attempt was made to discover significant ways of improving student attitudes toward science. Therefore, with this understanding in mind, although the design which employed different teachers in the two groups could bring into question the validity of the findings, the results of the study nevertheless provide clear evidence of change in student attitudes toward science. In other words, this study was more like an action research. It tested the effectiveness of integrating history into science teaching and obtained evidence of change in student attitudes toward science throughout the period of teaching.

III. Result

1. Quantitative Part

The Cronbach alpha reliability of the WASP for the pre- and post-tests was 0.87 and 0.92 respectively. This reveals the high consistency of the measurements of the instrument. The pre- and post-tests of the WASP mean scores and standard deviations of the experimental and control groups are shown in Table 1. It can be seen that both groups made progress in their attitude-toward-science scores. The further ANCOVA result (Table 2) reveals that the progress of the experimental group was significantly higher than that of its counterpart at the $p<0.05$ confidence level.

Additional dependent t-test results shown in Table 3 indicate that both groups made significant progress in their WASP score. The experimental group improved 9.24 ($p<0.01$) while the control group produced a gain of 2.70 ($p<0.05$).

2. Qualitative Part

After each of the three historical cases were taught, six students were randomly selected as interview subjects to determine their perceptions and attitudes toward the supplemental teaching material. All of the six students reacted positively toward the material. For example, student A liked the historical descriptions because they helped him to better understand how scientific theories are created and accepted by people.

> Investigator: This week we reviewed the development of Boyle's law. Since this is the first time I used this material, I would like to get some feedback from you in order to make further improvement in the future. Tell me, how do you like it ?
> Student A: I like the material.
> Investigator: Why do you like it ?
> Student A: It makes me to think more about what science is. When I was in high school, all the concepts and knowledge were represented as final products to be learned. After learning about the development of Boyle's law, I realize that scientists argue with other scientists who have different beliefs.

Table 1. WASP Means and SDs of the Two Groups

test	experimental group			control group		
	N	mean	SD	N	mean	SD
pre-test	30	171.10	11.89	31	174.19	9.72
post-test	25	181.28	14.21	30	177.33	11.72

Table 2. ANCOVA Result of the WASP Score between the Two Groups

sources	df	SS	MS	F	P
between groups	1	466.96	466.96	4.56	*
pre-test	1	3512.13	3512.13	34.32	**
residual	52	5321.58	102.34		

*: $p<0.05$ **: $p<0.01$

Table 3. Dependent t-tests of the WASP Scores

group	N	mean difference	t	p
experimental	25	9.24 (2.71)[a]	3.41	**
control	30	2.70 (1.22)	2.22	*

a: Numbers in ( ) are standard deviations.
*: $p<0.05$ **: $p<0.01$

Student B was impressed by the mistakes made by previous scientists (in the case of atmospheric pressure). She liked that part because it helps her to clarify in her mind the target concept and to avoid the same mistake.

> Investigator: What makes you like the history of science ?
> Student B: It helps me to understand air pressure.
> Investigator: How does it help you ?
> Student B: Frankly speaking, I had the same misunderstanding as the previous scientist did who thought that air would exert no pressure when it was enclosed in a container. The description of how Boyle disproved this idea helps me avoid the same error. I am happy to know that scientists make mistakes, too!

Students C accepted the history of chemistry because it describes the developmental and societal nature of science.

> Investigator: In the topic of atoms and molecules, what

differences do you see between high school chemistry and the college general chemistry we just studied ?
Student C: I have learned more about how the concept of the molecule is distinguished from the concept of the atom from college general chemistry.
Investigator: Which one do you like better ?
Student C: College general chemistry.
Investigator: What are your reasons ?
Student C: It was interesting to find out that it took earlier scientists 50 years to distinguish the difference between the atom and the molecule.

IV. Discussion and Implication for Chemistry Teaching

The result of positive student attitude change in both of the groups is encouraging to those who are interested in the history of science and in curriculum design which relates chemistry to the real world. The textbook used in this study presents chemistry in a way that helps students understand and resolve social problems. The three cases of history describe how scientific concepts develop. All together, they significantly promoted the students' attitudes toward science in this study. As mentioned earlier in the "Introduction" section, research studies previously found not only that students lose interest in science as they progress in school, but also that students are less interested in science after taking a science course than they were at the beginning of the course (Yager, 1986). It is not easy to motivate positive student attitudes simply by continuing to emphasize terms and laws, or by continuing to test for mastery. If chemistry teachers and science educators intend to foster in their students' positive attitudes toward science, the way of integrating historical materials into classroom instructions as reported in this study provides an additional alternative approach to teaching chemistry.

Both types of data collected, quantitative and qualitative, offer substantial evidence that the teaching of historical cases in chemistry made a significant contribution to the students' positive change of attitudes toward science. Although from the quantitative results, one may suspect that the main effect (positive student attitude change) could have been due to the teacher instead of the treatment (the history of science), the fact that the qualitative results from interviews corroborated the results from the questionnaire quantitative analysis provides a clearer picture indicating that the experimental students liked the historical material, and that their appreciation for science increased. Researchers in the field of the history of science have suggested potential benefits of integrating the history of science into teaching (Conant, 1957; DeBerg, 1989; Duschl, 1985; Duschl 1990; Matthews, 1994). This study followed their suggestion and further confirmed through empirical data the initial benefit of promoting student attitudes toward science. Nevertheless, there is much more work to be done in the future. For instance, additional studies larger in scale or with control of the teacher effect are encouraged to confirm its practical utility.

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以科學史提升大學生對科學的態度

林煥祥

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摘　要

本研究探討了在大一普通化學中融入科學史教學，是否具有提升學生「對科學的態度」之效益。共有兩個非化學系的班級合計 61 位大一學生參與這個具有行動研究精神的準實驗研究。在爲期一年的期間，研究者將三個科學史的單元融入現有課程中，對實驗組的學生進行教學。學年結束時，將量的數據進行共變數分析。以後測之科學態度量表得分爲依變項，前測得分爲共變項，所得結果發現，實驗組學生「對科學的態度」表現顯著優於控制組。另外由晤談所得之質的資料，也可看出科學史的教學具有正面之效益。

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   (4) Indicate units of measure in parentheses in the heading of each column. Do not change the unit of measure within a column.
9. Acknowledgments
   Acknowledgments should be stated using a minimum of words and given as a paragraph at the end of the text. Acknowledgments to individuals usually precede those for grant support. Names of grant sources should be spelled out.
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   (1) References should be cited in the text by the last name of the author and year. If there is more than one reference to the same author(s) and the same year of publication, the references should be differentiated by a, b, etc. e.g., (Jones, 1996; Jones & Smith, 1996; Jones, Smith, Chang, & Lee, 1992; Reed, 1994a, 1994b); Jones (1996) suggested that ......; Jones & Smith (1996) reported that ......; ...... reported by Smith, Jones, & Chen (1995) [first citation]; ...... as described by Smith *et al.* (1995) [subsequent citations].
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      (i) For journals*
         Galotti, K. M., & Komatsu, L. K. (1989). Correlates of syllogistic reasoning in middle childhood and early adolescence. *Journal of Youth and Adolescence*, **18**, 85-96.
         Johnson-Laird, P. N., Byrne, M. J., & Tabossi, P. (1989). Reasoning by model: The case of multiple quantification. *Psychological Review*, **96,** 658-673.
      (ii) For books*
         Kuhn, T. S. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago, IL: University of Chicago Press.
         Gentner, D., & Gentner, D. R. (1983). Flowing waters or teeming crowds: Mental models of electricity. In: D. Gentner & A.L. Stevens (Eds.), *Mental models* (Vol. 5, pp. 865-903). Hillsdale, NJ: Lawrence Erlbaum.
      (iii) For theses*
         Brush, S. (1993). *A case study of learning chemistry in a college physical science course developed for prospective elementary teachers.* Unpublished doctoral dissertation, Florida State University, Tallahassee, FL.
      (iv) For conference papers*
         George, S. E., & Grace, J. R. (1980). Entrainment of particles from a pilot scale fluidized bed. Paper presented at the meeting of the Third International Conference on Fluidization, Henniker, NH.
         Edmondson, K. M., & Novak, J. D. (1992). Toward an authentic understanding of subject matter. In: S. Hills (Ed.), *Proceedings of the Second International Conference on the History and Philosophy of Science and Science Teaching* (pp. 253-263). Kingston, Ontario: Queen's University.
      (v) For technical reports*
         Tiller, F. M., & Leu, W. F. (1984). *Solid-liquid separation for liquefied coal industries: Final report for RP-1411-1* (EPRI AP-3599). Palo Alto, CA: Electric Power Research Institute.
      (vi) For patents*
         Verschuur, E. (1978). Agglomerating coal slurry particles. U.S. Patent 4, 126, 426.

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Impacts of an Inquiry Teaching Method on Earth Science Students' Learning Outcomes and Attitudes at the Secondary School Level

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Abstract

This paper summarizes two companion studies that were designed to investigate the impacts of an inquiry teaching method on Earth science students' achievement and attitudes toward Earth science in secondary schools. Subjects were 557 Earth science students (9th grade) enrolled in 14 Earth science classes. Two Earth science units including topics of astronomy and meteorology were developed and taught using the inquiry-oriented instructional model. The experimental group (n=284) received inquiry-oriented instruction while the control group (n=273) received a more traditional approach over an eight-week period. The dependent variables were measured through the use of (1) the *Earth Science Achievement Test* to assess Earth science students' achievement and (2) the *Attitudes toward Earth Science Inventory* to measure students' attitudes toward Earth science. Quantitative data were collected on students' pre- and post-treatment achievement and attitudes toward Earth science measures. Analysis of covariance revealed that (a) the inquiry-oriented instructional method produced significantly greater achievement among ninth grade Earth science students than the conventional teaching approach on both astronomy content (F=9.45, p<0.01) and meteorology content (F=8.41, p<0.01), and that (b) students in the experimental group developed significantly more positive attitudes toward Earth science than did those in the control group (F=9.07, p<0.01). In light of these two studies, it is therefore suggested that students can learn Earth science through the inquiry approach. In addition, these findings support the notion that effective instruction of Earth science, such as using inquiry-oriented instruction, should be proposed and implemented in secondary schools.

Key Words: inquiry, teaching methods, student attitudes, achievement, earth science

I. Introduction

According to the 1996 *National Science Education Standards* developed in the U.S. (NRC, 1996), "teaching science as inquiry provides teachers with the opportunity to develop student abilities and to enrich student understanding of science" (p. 121). Inquiry-oriented instruction in the literature has been closely associated with other teaching methods, such as problem-solving, laboratory and cooperative learning, and discovery instruction. These methods are commonly referred to as the inquiry approach, which often places an emphasis on the extensive use of science process skills and independent thought.

Inquiry-oriented teaching practices have long been proposed and have prevailed in main-stream classrooms. Research findings on the comparative efficacy of inquiry vs. traditional instruction are conflicting. Many studies on the use of inquiry-oriented teaching approaches in typical secondary school classrooms have shown some positive effects on students' content-achievement (Chang & Barufaldi, in press; Ertepinar & Geban, 1996; Gabel, Rubba, & Franz, 1977; Geban, Askar, & Ozkan, 1992; Hall & McCurdy, 1990; Henkel, 1968; Mulopo & Fowler, 1987; Richardson & Renner, 1970; Russell & Chiappetta, 1981; Saunders & Shepardson, 1987), on content retention (Schneider & Renner, 1980), on laboratory skills or science process skills (Basaga, Geban, & Tekkaya, 1994; Mattheis & Nakayama, 1988;

110

Tobin & Capie, 1982), and on attitudes toward science or science activities (Gabel, Rubba, & Franz, 1977; Kyle, Bonnstetter, & Gadsden, 1988; Shepardson & Pizzini, 1993). On the other hand, some research has found that inquiry-oriented teaching strategies had no significant effect on the cognitive achievement of learners (Oliver, 1965; Orr, 1968), on the learning of science process skills or on cognitive development (Germann, 1989). Consequently, it is worthwhile to explore whether an inquiry-oriented instructional method will have any effects on Earth science students' learning outcomes at the secondary school level.

Earth science, which consists of geology, meteorology, astronomy, and oceanography, is one of the science subjects most relevant to students' everyday lives. Accordingly, the *National Science Education Standards* (NRC, 1996) embrace Earth and Space Science as one of the eight categories of content standards along with Physical Science and Life Science. Learning Earth science not only interests students in probing the mysteries of nature, but also can inspire students' concern for environmental issues, such as acid rain, destruction of the ozone layer, and groundwater pollution. Still and all, most of the aforementioned research studies on inquiry-oriented teaching strategies have emphasized life science, physics, and chemistry; only a few studies (for example, Chang & Barufaldi, in press; Russell & Chiappetta, 1981) have focused on Earth science content. Therefore, it is important to explore whether an inquiry-oriented instructional method will have positive effects on Earth science students' learning outcomes at the secondary school level.

Wise & Okey (1982) found the strongest effects for biology and *weakest for Earth science* in a meta-analysis of the effects of various teaching strategies on student achievement. Shymansky, Kyle, & Alport (1983) also reported a meta-analysis of the impact of the NSF-reform inquiry-oriented science curricula on student performance and found that the science curricula improved students' science achievement and process skills as well as attitudes toward science. Effect sizes were largest for biology and *weakest for Earth science* and chemistry. Shymansky, Hedges, & Woodworth (1990) further employed refined statistical procedures to re-synthesize the aforementioned research, and showed that the mean effects on four performance clusters (achievement, process skills, problem solving, and attitude) were significantly positive. It is, therefore, necessary and important to investigate the impacts of an inquiry-oriented instructional method on the achievement and attitudes of students with an emphasis on Earth science content.

Many researchers in the area of Earth science education have attempted to develop or employ inquiry-oriented instructional methods in the college. For example, Stefanich (1979) implemented an inquiry-oriented teaching method that encouraged students to gather data in order to interpret geological events. Starr (1995) also examined the effects of cooperative-learning strategies on geology achievement and students' attitudes toward science. The results indicated an improvement in achievement and enhancement of student attitudes toward science. While some previous research has shown that an inquiry-oriented instructional method can improve students' science process skills and content achievement, research on explicit teaching or traditional instruction has also revealed that student achievement is improved among certain kinds of students and for selected kinds of instructional objectives (Waxman, 1991). After reviewing research on inquiry-oriented teaching, Flick (1995) stated that: "Research on inquiry-oriented instruction has produced mixed results with the clearest effects occurring with more capable students, who have well trained teachers, and a supportive classroom environment" (p. 17). Accordingly, it is interesting and important to make a comparison between inquiry-oriented instruction and the traditional teaching method in terms of their effects on students' learning of Earth science content in typical classroom settings.

II. Purpose

The purpose of this paper was to detail two companion studies that were designed to investigate the impacts of an inquiry teaching method on ninth grade Earth science students' achievement and attitudes toward Earth science in secondary schools. The Phase I Study developed a teaching unit on astronomy and employed an inquiry-oriented instructional model to introduce this subject-matter. The Phase II Study utilized an identical teaching strategy but focused on meteorology.

III. Method

1. Subjects

The participants in these two studies were 557 ninth grade Earth science students enrolled in 14 Earth science classes and four volunteering Earth-science teachers who taught the above classes at four public junior high schools located in the northern region of Taiwan. These four junior high schools shared similar features, including similar student populations and

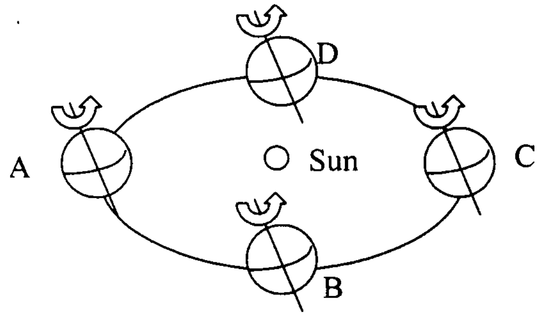

Fig. 1. Revolution of the Earth around the Sun.

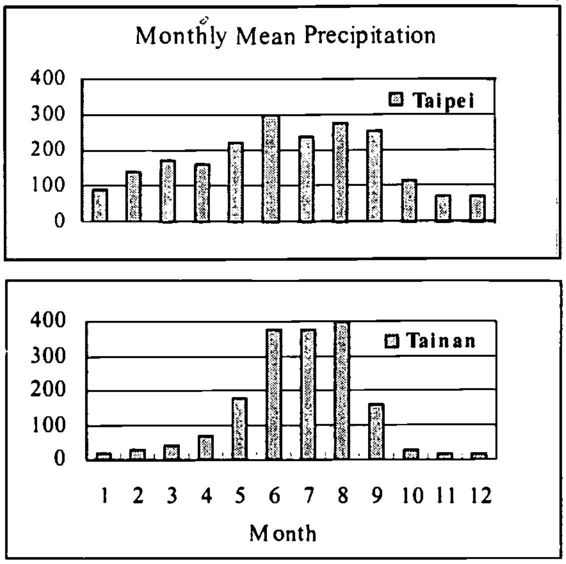

Fig. 2. Monthly mean precipitation in Taipei and Taiwan measured from 1958 through 1988.

school administration. Seven intact classes (n=284) were randomly assigned to the inquiry-oriented instruction group; the other seven classes (n=273) were randomly assigned to the traditional-lecture group. These students were typical secondary school students about 15 years of age; gender was equally distributed among the classes.

2. Instrument

The *Earth Science Achievement Test* was constructed and designed to measure Earth science content achievement and to assess knowledge, comprehensive, and application level objectives of the cognitive domain. The instrument consisted of selected or modified items from the following tests: (1) Taiwan Entrance Examination for Senior High School (TEESHS) – astronomy and meteorology topics, (2) Educational Progress in Earth Science Learning (EPESL), and (3) "Let's Review: Earth Science" (Deneck, 1995). The test items were all specifically related to textbook content and equally distributed among topics during the treatment periods. Content validity was established by a panel of experts, including four professors from the Department of Earth Sciences, National Taiwan Normal University. These experts checked the correspondence between the treatment and test item contents, and determined that the nature of the test items was strongly related to the important concepts introduced in the instruction.

After conducting item analysis, thirteen test items was selected and used as a pretest and twenty-six test items were included in the posttest for the Phase I Study (the Astronomy Content Study). The Cronbach alpha method was used to estimate the reliability coefficients of both the pretest and posttest. Reliability coefficients of 0.45 for the pretest and 0.82 for the posttest were reported for the Phase I Study. Two sample multiple-choice items were used in the posttest as follows:

Look at this diagram that shows revolution of the Earth around the sun. Then choose the answer that best fits each of the questions below (Fig. 1.):

(1) When the Earth moves to position C, what season is it in Taiwan? (1) spring (2) summer (3) autumn (4) winter.

(2) When the Earth moves from C to D, what kind of phenomena will happen in terms of the duration of daytime and nighttime in a day? (1) the same length (2) daytime is increasing (3) daytime is decreasing (4) nighttime is always longer than daytime.

As for the Phase II Study (the Meteorology Content Study), the pretest contained eight test items and the posttest consisted of twenty-four test items. Reliability coefficients (Cronbach alpha) of 0.40 for the pretest and 0.78 for the posttest were estimated for the Phase II Study. The following is an example of the test items used in the posttest of the Phase II Study:

The following two climate graphs represent monthly mean precipitation in Taipei and Tainan measured from 1958 through 1988. Please answer the following question based on your observation from the graphs (Fig. 2.).

Which one of the following descriptions is inaccurate? (1) Even the monthly mean precipitation for November and December in Taipei is the same, we should not infer that the length of rainy days is also the same during those two months. (2) The monthly mean precipitation in June is more than that in August in Taipei, yet, it does not necessarily mean that this will happen every year. (3) Precipitation in Tainan occurs primarily from May through September. (4) Precipitation from April through September for both places accounts for less than half of their respective annual precipitation.

The instrument was further classified into three categories (factual, comprehensive, and integrated items) which correspond to Bloom's Taxonomy (1956) of knowledge (factual), comprehension and application (integrated) levels. The same panel of aforementioned experts, who were knowledgeable about the criteria of these categories, classified these items into three categories with high agreement. Consequently, the Phase I Study posttest included five items at the factual level, sixteen items at the comprehensive level, and five items at the integrated level. The Phase II Study posttest contained five items at the factual level, eleven items at the comprehensive level, and eight items constructed at the integrated level. The classification of test items aimed at investigating students' levels of understanding and achievement of Earth science content.

The *Attitudes toward Earth Science Inventory* consisted of 13 items designed to measure student' attitudes toward Earth science, including class participation, confidence level on the subject of Earth science, and learning interest in Earth science. This instrument (Appendix) was constructed by modifying survey items from an existing questionnaire: the *Attitude toward Biology Instrument* developed by Cheng and Yang (1995). Thirteen items were selected, modified and used as both a pretest and posttest to determine students' attitudes toward Earth science. Reliability was established through internal consistency. The Cronbach reliability coefficient was estimated to be 0.84 for the pretest and 0.85 for the posttest, respectively.

3. Treatment

It is important to distinguish between "inquiry-oriented" and "traditional" instruction in these two studies. Welch, Klopfer, Aikenhead & Robinson (1981) identified one major theme in science inquiry skills, which includes observing and interpreting data. The inquiry-oriented instructional method developed and employed in these two studies emphasized gathering and interpreting data by students in a cooperative-learning setting with the goal of improving students' learning of Earth science content. In addition, students also critically examined data for relationships by interpreting related data and then drawing conclusions. Another key feature of the inquiry-oriented teaching is cooperative learning, including small group discussion. Small group discussion is intended to increase interaction between students and the instructional materials. During group discussion, students clarify their own ideas and communicate with each other.

The inquiry-oriented instruction and instructional units employed in the Phase I Study focused on astronomy. The treatment consisted of an approximately four-week period of Earth science instruction. Student engagement was followed by gathering information, recording what had been observed, and interpreting data generated from hands-on activities and group discussion. During one hands-on activity, for example, students were first provided a diagram showing a series of stick shadows under the Sun on March 21 or 22 (spring equinox) in Taiwan. Students were then asked to project (or plot) different locations of the Sun on a mini transparent celestial sphere for that specific day. After observing the various locations of the Sun in a day, students were required to interpret data and make explanations through group discussion. This activity was also repeated for June 21 or 22 (summer solstice), September 22 or 23 (autumnal equinox), and December 21 or 22 (winter solstice) for further comparison and interpretation purpose. Class presentation of group-discussion results and teacher's discussions with students were followed by the teacher's explanation of the Earth-Sun system. The most important characteristics of the lessons were "student-centered" activities designed to encourage students to become more skillful in using science process skills and to create better understanding of Earth science concepts. The instructor served as a facilitator in the learning process.

Inquiry-oriented instruction in the Phase II Study also emphasized students' hands-on, minds-on activities, which involved gathering and recording data as well as interpreting data and their relationships. The characteristics of the inquiry-oriented instruction employed in this study are the same as those described in the Phase I Study, yet the instructional units focused on meteorology content. The treatment consisted of another four-week period of Earth science instruction, emphasizing inquiry. It is noted that the inquiry-oriented instruction proposed in these studies did not exclude the use of textbooks or other instructional materials but emphasized active search processes employed by students. It is also noted that the instructional materials prepared for the experimental group were also provided to the control group as a placebo control.

The traditional instructional method in this study stressed direct lectures given by teachers, use of textbooks and other materials, and clear explanation of important concepts to students; occasional demonstrations and a review of the textbook topics were also included. The key feature of this "teacher-oriented" instruction was providing students with clear and detailed instructions and explanations. The teacher undertook the task of transferring science knowledge to students.

It is noted that each instruction group experienced the same topics (detailed below) and instructional time (eight weeks). The Earth science textbook copies for the eight-week period include the following units: Unit Nine - moisture and the atmosphere, convection currents, atmospheric pressure, air masses and weather fronts, weather map and weather, and climates; Unit Ten - the Earth-Sun system, the apparent movement of the Sun and the stars, the Earth's rotation and revolution, and seasons. Four weeks were allotted for Unit Nine, and four weeks were used for Unit Ten.

4. Design and Procedures

The experimental design for these two studies was a quasi-experimental non-equivalent control group design described by Campbell & Stanley (1966). Each instruction group participated in four weeks of instruction on astronomy (the Phase I Study), followed by another four weeks of instruction on meteorology (the Phase II Study). The *Earth Science Achievement Test* and the *Attitudes toward Earth Science Inventory* were administered to all the students at the beginning of the treatment as the pretests and were given again as the posttests at the conclusion of each respective instruction period. In addition, participating teachers were asked to write down a journal which described their personal perceptions toward the inquiry-oriented instruction and any problems they had encountered while implementing this specific teaching method in the main-stream classrooms. A number of variables were set constant in order to derive a statistical comparison between the experimental group and the control group. These variables were ninth grade Earth science students, similar school administration, the same participating teachers, and the same instructional content and duration in these two studies. The only variable for these studies was the inquiry-based instruction versus the traditional teaching method. The data were analyzed by employing analysis of covariance (ANCOVA) on posttest scores with the pretest as the covariate to determine any significant differences between the experimental group and the control group. ANCOVA was also conducted at the factual, comprehensive, and the integrated levels of the posttest measures to determine if there were significant differences between the two groups at these levels of understanding. The assumptions[1] of ANCOVA were first checked to insure that they were met in the analysis of covariance for these studies. Then these data were subjected to a 0.05 level of significant test. Tests of the assumptions for analysis of covariance (ANCOVA) and inferential statistical analyses were carried out using SPSS (Statistical Package for Social Sciences version 7.0).

Table 1. Summary of ANCOVA on Students' Achievement Scores for the Phase I Study

Posttest Level	Inquiry Groups Adjusted Mean (SD)	Traditional Groups Adjusted Mean (SD)	F
Factual Level	2.7(1.3)*	2.3(1.3)	8.44*
Comprehensive Level	9.0(3.6)*	8.1(3.6)	9.30*
Integrated Level	3.1(1.2)	3.0(1.3)	1.02
Total Items	14.7(5.3)*	13.4(5.4)	9.45*

*$p<0.01$

IV. Results

1. Phase I Study: Astronomy Content Study

Table 1 shows the results of ANCOVA and descriptive data analysis on students' achievement posttest scores. It is statistically indicated that subjects taught using the inquiry-oriented instructional method scored significantly higher than those taught using the traditional teaching method on Earth science content achievement (F=9.45, p<0.01) (total items). Additionally, significantly higher achievement scores for the experimental group were found at the factual (F=8.44, p<0.01) and comprehensive levels (F=9.30, p<0.01) of understandings. However, there were no significant gains in student achievement at the integrated level in the experimental group when compared with the control group (F=1.02, p>0.05).

[1] A conventional Barlet's test of homogeneity of variance indicated homogeneity among variance. Preliminary test for homogeneity of the regression slope performed significant test on interaction between the covariate and the variables. The results indicated that the assumption of parallelism of the regression slope was tenable because the F ratio yielded non significant values for all the variables.

Table 2. Summary of ANCOVA on Students' Achievement Scores for the Phase II Study

Posttest Level	Inquiry Groups Adjusted Mean (SD)	Traditional Groups Adjusted Mean (SD)	F
Factual Level	2.91(1.34)*	2.95(1.57)	0.11
Comprehensive Level	7.33(2.17)*	6.77(2.39)	9.63*
Integrated Level	3.74(1.84)	3.22(1.70)	13.44*
Total Items	14.07(4.40)*	13.05(4.87)	8.41*

*$p<0.01$

Table 3. Summary of ANCOVA on Students' Achievement Scores for the Phase II Study

Posttest Level	Inquiry Groups Adjusted Mean (SD)	Traditional Groups Adjusted Mean (SD)	F
Participation	1.81(2.30)*	1.34(2.35)	9.05*
Confidence	1.43(2.49)*	1.02(2.63)	5.52*
Learning Interest	1.51(1.60)	2.00(1.20)	1.04
Total Items	4.77(5.22)*	3.73(5.62)	9.07*

*$p<0.01$

2. Phase II Study: Meteorology Content Study

The results of ANCOVA and descriptive data analysis on students' meteorology achievement are summarized in Table 2. It is statistically shown that students exposed to the inquiry-oriented instructional method performed significantly better than those exposed to the more traditional approach (F=8.41, $p<0.01$) as shown in Table 2 (total items), especially at the comprehensive (F=9.63, $p<0.01$) and integrated levels (F=13.44, $p<0.01$). Nonetheless, no significant differences were found between the experimental groups and the control groups in the students' meteorology achievement at the factual level (F=0.11, $p>0.05$).

3. Attitudes toward Earth Science

Descriptive data and the results of ANCOVA analysis of students' attitudes toward Earth science are shown in Table 3. It is statistically revealed that the inquiry-oriented instructional method did produce significantly more positive learning attitudes among Earth science students than did the traditional teaching method (F=9.07, $p<0.01$) (total items). Furthermore, the inquiry teaching approach significantly promoted positive attitudes toward Earth science among the experimental group at the participation (F=9.05, $p<0.01$) and confidence levels (F=5.52, $p<0.01$). Still and all, no significant differences between the groups were found in terms of score gains at the learning interest level (F=1.04, $p>0.05$), as measured by *Attitudes Toward Earth Science Inventory*.

After analyzing data obtained from *Attitudes toward Earth Science* measure, we found that most students in the experimental group like the hands-on, investigative, and problem-solving activities in the Earth Science class. They also feel confident in solving Earth science problems and expressing themselves in the class.

4. Teachers' Perceptions toward the Treatment

Information obtained from participating teachers' journal writing revealed that most of the teachers appreciated and admired this type of instructional method. However, they admonished that this kind of teaching approach should be well prepared when employing it in the main-stream classrooms. Besides, selection of appropriate topics to introduce when using this kind of instructional method is also important. As one teacher stated that

> This kind of instruction (inquiry) is beneficial for students in terms of enhancing their thinking skills, however, implementing it requires more efforts and preparations.

V. Discussions and Implications

1. Content Achievement

After eight weeks of inquiry-oriented instruction, the experimental group had significantly higher science achievement scores than did the control group. It may be that pupils exposed to the treatment had the opportunity to observe, record, and interpret data on their own during hands-on investigative activities. Correspondingly, the basic and integrated science process skills emphasized in these studies might have helped the experimental group learn the Earth science content better compared to the control group. The results of these two companion studies are consistent with those of other studies, which showed that inquiry-oriented instruction produced positive outcomes in student science achievement (Bredderman, 1985; Ertepinar & Geban, 1996; Gabel, Rubba, & Franz, 1977; Geban, Askar, & Ozkan, 1992; Henkel, 1968; Mulopo & Fowler, 1987; Richardson & Renner, 1970; Russell & Chiappetta, 1981; Saunders & Shepardson, 1987). Furthermore, these two studies generate evidence to support the notion that the inquiry-oriented

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approach is more effective in enhancing *learning of Earth science concepts* than is a more traditional teaching method.

The results of the Phase I Study at the integrated level showed no significant differences in the achievement of students between the experimental group and the control group. It may be that the nature of the integrated test items for Astronomy was difficult for students or that the number of integrated items (only five items at this level) was not sufficient to obtain a statistical distinction between the experimental and control groups.

The Phase II Study revealed no significant differences in the achievement of students at the factual level between the experimental group and the control group. Subjects taught using the inquiry-oriented instructional method did not outperform at the factual level those taught using the more traditional approach, perhaps because rote memorization aided performance at that level. On the other hand, the inquiry-group students did perform significantly better in terms of achievement for the upper-level items (the comprehensive and integrated levels) than did traditional-group students, apparently due to the emphasis of the instruction on science process skills and independent thought among students. The results of the Phase II Study also lend support to those of previous studies, which recorded improved science achievement among pupils at higher cognitive levels of Bloom's Taxonomy (Chang & Barufaldi, in press; Chiappetta & Russell, 1982; Ertepinar & Geban, 1996; Gabel, Rubba, & Franz, 1977; Geban, Askar, & Ozkan, 1992; Henkel, 1968; Mulopo & Fowler, 1987; Saunders & Shepardson, 1987).

The hands-on and minds-on activities used during the inquiry-oriented instruction seemed to enhance Earth science content achievement since they provided students with first-hand experience in doing science and opportunities to collect and interpret data and to make valid conclusions. Therefore, science teachers and educators should continue to promote inquiry-oriented instruction in the classroom. Moreover, students should be provided with opportunities to search and collect information, interpret and analyze data, draw conclusions, and share or communicate ideas at the secondary level.

2. Attitudes toward Earth Science

Students in the experimental group showed significantly more positive attitudes toward Earth science than did those in the control group. The results of these two studies are consistent with those of other studies (Gabel, Rubba, & Franz, 1977; Kyle, Bonnstetter, & Gadsden, 1988; Shepardson & Pizzini, 1993), which found that inquiry-oriented instruction or curriculum materials significantly improved attitudes toward science among students. Welch, Klopfer, Aikenhead, & Robinson (1981) stated that: "Thus, in an inquiry classroom there is a time for doing... a time for reflection... a time for feeling... and a time for assessment." (p. 35) It seems that inquiry activities might help students realize that they are doing and feeling real science, leading to more positive attitudes toward Earth science.

It is noted that the learning interest of these students not significantly different between two groups, perhaps because the students were not familiar with this type of instruction and were under tremendous stress due to an upcoming unified entrance examination. Nevertheless, participation and confidence levels were increased since the inquiry-oriented instruction provided the students with hands-on and minds-on activities and required them to work on their own rather than depend upon the teacher's explanations. The students assumed the role of "knowledge pursuer"; therefore, their attitude scores increased at the class participation and confidence levels of the affective domain.

VI. Conclusions

The inquiry-oriented instruction used in these two studies emphasize on student inquiry, interpretation of data, group discussions, and cooperative learning; these strategies might help develop students' higher mental skills, improve their attitudes toward Earth science, facilitate learning of Earth science concepts and, therefore, raise their levels of Earth science content achievement. Science education standards recently proposed in the U.S. state that all students should both learn about scientific inquiry and learn science through inquiry (NRC, 1996). The results of this pair of studies support this idea. It is, therefore, suggested that it can be beneficial for students to learn science through the inquiry approach. Likewise, the inquiry-oriented teaching method should be used as a primary vehicle to assist learning of Earth science in secondary schools. It is also believed by the researchers that effective instruction in Earth science, such as the inquiry-oriented instruction, should emphasize "student-centered activities" instead of "teacher-centered lectures" in secondary schools.

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Appendix

1. Earth science classes are: (1) very interesting (2) interesting (3) no opinion (4) not interesting (5) not interesting at all
2. My perception toward the "hands-on" activities in the class: (1) strongly like (2) like (3) no opinion (4) dislike (5) strongly dislike
3. I would rather listening to the teacher than doing activities in the class: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree
4. If there is an Earth science class session today, I will feel: (1) strongly boring (2) boring (3) no opinion (4) interested (5) very interested
5. My perception toward the "investigative" and "problem-solving" activities in the class: (1) strongly like (2) like (3) no opinion (4) dislike (5) strongly dislike
6. I can learn a lot of knowledge in the Earth science class: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree
7. I feel confident in the Earth science class: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree
8. I can solve simple problems on astronomy and meteorology content: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree
9. I have a lot of opportunities to fully express myself in the Earth science class: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree
10. The "investigative" and "problem-solving" activities in the class are annoying: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree
11. I am interested to learn more Earth science topics: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree
12. I think that Earth science concepts are easy to understand: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree
13. I do not feel learning and thinking in the Earth science class: (1) strongly agree (2) agree (3) no opinion (4) disagree (5) strongly disagree

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探究式教學法對國中學生地球科學學習成效與態度之影響

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摘　要

本文主旨在綜結兩個並行研究的成果。這兩項研究主要探討探究式教學法對中等學校學生的地球科學學習成就和其對地球科學態度之影響。共有來自十四個班級五百五十七位國中三年級的學生參與研究。研究中運用探究式教學法來教授天文及氣象兩個地球科學的單元。實驗組學生（n=284）接受八週的探究式教學模組，而控制組（n=273）則在同一時間內接受傳統式的教學法。研究中的兩項依變數採用下列兩種量表來測量：(1)地球科學學習成就測驗用來評估學生在地球科學上的學習成就；(2)地球科學態度量表用來探究學生對地球科學之觀感與態度。利用上述量表分別對學生實施前測及後測以取得量化之數據。根據共變數分析（ANCOVA）的結果顯示：(a)以探究爲基礎的教學法比傳統式教學法更顯著地增進學生在天文單元（F=9.45, p<0.01）以及氣象單元（F=8.41, p<0.01）的學習成就；(b)實驗組的學生比控制組的學生對地球科學有較顯著且正面的態度（F=9.07, p<0.01）。研究結果證明了學生可以經由探究的方式來學習地球科學。此外，研究之發現亦可支持以下的論點：這類具有成效之探究式教學法應該在中等學校地球科學課堂上全面的推展。

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Teaching Competencies Assessment Approaches for Mathematics Teachers

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Abstract

The purposes of this study were: (1) to contruct a list of assessment items; (2) to establish assessment models; and (3) to develop evaluation instruments so that there would be a direction for better mathematics teacher preparation. The research process included three steps: first, to review the literature on the characteristics of a competent Mathematics teacher's basic skills; second, to develop assessment models and evaluation instrument; and third, to design teaching simulation situations on video to assess student teachers' mathematics instruction performance. The simulation situation were evaluated from four dimensions, teaching skills, organization and presentation of materials, management of the learning environment, and teaching attitudes.

Key Word: teaching assessment, teaching competency, mathematics teacher, evaluation instrument

I. Introduction

"The Teacher Preparation Acts" were enacted in November 1979 and have been in force for a decade. Owing to the rapid change of the environment, "The New Teacher Preparation Acts" became effective in January 1994.

The purposes of the new acts are to provide various ways to educate excellent teachers in various disciplines and to improve the qualities of school teachers which can reflect social inquiry. Therefore, opening educational courses to meet this aim is no longer the mission of only the National Normal Universities in Taiwan, but also that of each college.

At the present time, a student teacher's certificate is issued after he or she received a Learning Permit. This process is regulated in the New Teachers Preparation Acts. However, the Teachers Preparation Acts only state that issuing of an initial certificate is based on the inspection of student-teacher's official papers. There is no clear guideline for issuing an advanced teacher's certificate. Under these circumstances, it must develop a set of teaching assessment instruments to measure a student teacher's teaching competency.

II. Purposes of the Study

The followings were the main purposes of the study:

(1) to contruct a list of assessment items for mathematics teachers;
(2) to establish assessment models for mathematics teachers; and
(3) to develop evaluation instruments for mathematics teachers.

III. Literature Review

1. Basic Teaching Competency in Mathematics

Many studies have investigated the teacher knowledge and ability of mathematics teachers. Fennema and Franke (1992) built up a model for examination and discussion on teachers' knowledge as it occurs in the context of the classroom. The model, which shows interactive and dynamic nature of teacher knowledge, includes the components of teacher knowledge of the content of mathematics, knowledge of pedagogy, knowledge of students' cognitions, and teachers' beliefs.

Shulman (1986, 1988) also proposed a frame-

119

work for analyzing teachers' knowledge that distinguished between different categories of knowledge: subject-matter knowledge, pedagogical content knowledge, and curricular knowledge. The Pedagogical Content Knowing (P.C.K g) approach, based on Shulman's (P.C.K.) approach to teaching attitudes and teaching continuous features, are provided by Cochran *et al.* (1993). This approach emphasizes that a teacher's knowledge and ability should include four aspects: (1) knowledge of a particular subject, (2) knowledge of common teaching ability, (3) knowledge of students' backgrounds (such as students's learning ability, age ..) and (4) knowledge of the teaching environment (including social, political and cultural aspects).

In addition, Krainer (1994) also proposed four dimensions of professional mathematics knowledge of mathematics teachers. They are abilities and attitudes in action, reflection, autonomy and networking. The teacher trainer should know whether these abilities and attitudes can impact teachers' self-growth in their teaching experience.

Leou (1995) in his "Mathematics and Science Teachers preparation," mentioned that the teaching behavior evaluation instrument was applied to assess the teaching competency during teachers' practice. This evaluation instrument focuses on: (1) the teacher's teaching skills, (2) the material's organization and presentation, (3) the learning environment created between students and teachers and (4) the teacher's teaching attitudes as four crucial aspects of teacher training.

2. Analysis of Assessment Model for Prospective Student Teachers

The implementation of the assessment models in each country has a different standard. Some states in the U.S. have set up the supportive team to create assessment files for each preservice teacher and observe their teaching performance in each class. After evaluation, teachers are graded based on their teaching competencies and skills. In England, the assessment made by local educational brueau includes classroom management, knowledge of subject-matter, teaching organization and skills as well as social relationships. After the evaluation, the results are submitted to the highest educational bureau and graded into three levels "qualified" "six months pending" or "disapproved". In France, student teachers who do practice teaching and receive a certificate are required to take an educational certificate exam in order to become qualified teachers. The contents of the test include oral and written tests. Student teachers' teaching performance will be a part of grade to become qualified teacher at the same time.

In Taiwan, the eighth and ninth issues of the Teachers' Education Law state two types of evaluations for student teachers' teaching performance: regular evaluation and semester evaluation. Both scores must be over sixty and the final grade is an average of the two. The aspect of regular evaluation focuses on morality, service attitudes, spirit of respect, social communication, teaching ability, and willingness to help students. The academic-year evaluation includes a plan for teaching practice and reflections on teaching practice or reports on special topics. The methods of evaluation are an oral test and a practice teaching.

According to the New Teacher Preparation Acts, the local educational bureau is responsible for giving the final exam. Therefore, it is important that we should refer to the assessment experience from other countries so that the content for evaluation and the standards for passing the requirements will be appropriate and meet the needs of our society.

The teaching simulation situation videotapes present the authentic classroom situations through sound and visual elements. To eliminate the shortcomings of traditional written tests, videotape presentation is used to directly evaluate teachers' teaching ability, feasibility of course design and problem solving skills.

This study selected important items from the mathematics teaching competency assessment items to make teaching simulation situation videotapes. Then, based on these items the teaching simulation situations were formed. The features of this study included: (1) replacement of the written test, (2) simulation of the real class situations; and (3) evaluation of teachers' teaching competencies and professional knowledge.

In terms of teachers' examination, each item evaluated matched a different topic; therefore, time limitations and simulated situations could be flexibly chosen depending on real needs.

IV. Method

The Delphi method and classroom observation technique were applied in this study. At the beginning, based on the characteristics of excellent Mathematics teachers and their teaching ability developed during practice in recent years, we attempted to construct a list of assessment items. Second, we invited the Delphi committee, composed of senior teachers, principals, education superintendents and instructors, to revise and redevelop forty-six assessment items. They also helped develop assessment models and evaluation instruments. Based on the experts' and the practitioners' opinions, the reliability and the validity were thus established.

The following will illustrate: (1) the structure of the assessment and teacher training steps, (2) the research designing, and (3) the procedure for designing teaching simulation situations on videotapes.

1. The Structure of the Mathematics Teaching Assessment and Teacher Training Steps

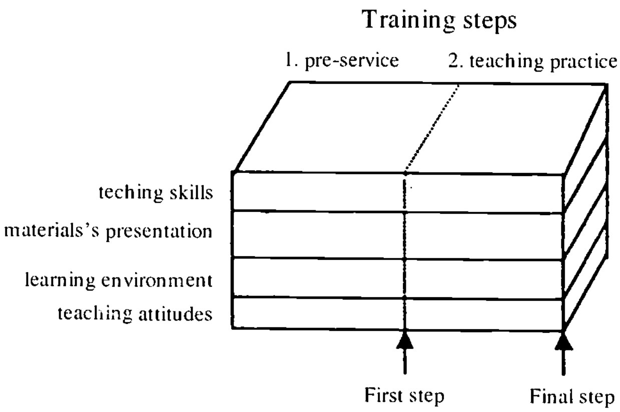

Fig. 1. Structure of teaching assessment and training steps.

2. Research Design

See Fig.2.

3. Procedure for Designing the Teaching Simulation Situation Videotapes

See Fig.3.

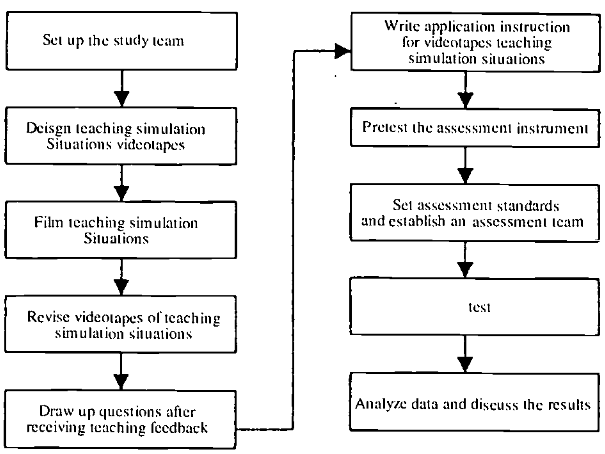

Fig. 3. Procedure for designing the videotapes.

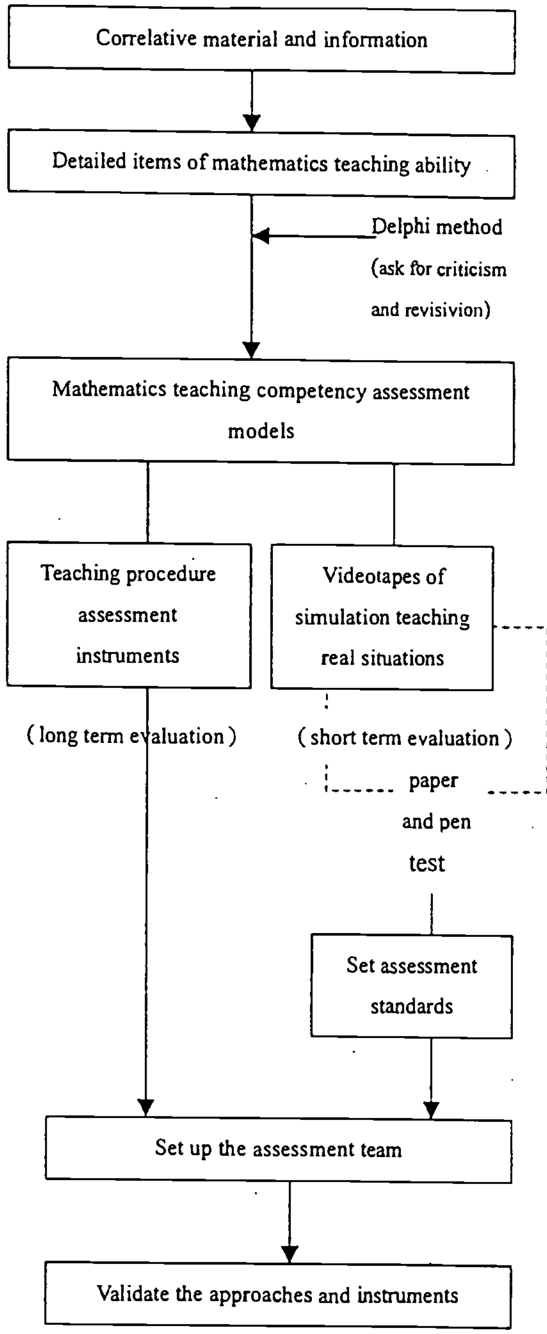

Fig. 2. Procedure for designing the study.

V. Results

For the time being, three main goals have been accomplished:

1. Establishment of the teaching competency assessment items for mathematics teachers,
2. Establishment of the assessment model for math-

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ematics teachers, and
3. Completion of teaching simulation situation videotapes as the assessment instrument.

The following tables are the guideline of the teaching competency assessment items:

Table 1. Teaching Competency Assessment Items for School Mathematics Teachers

Demension 1. Teaching Skills

1. Clearly point out the learning obejctives and procedures for each topic to students.
Items 1.1.1: Teachers present clear learning objectives before teaching.
1.1.2: Students are told the main learning procedures for topics.
1.1.3: Students are told the purpose and contents of each topic.

2. Choose proper teaching strategies which will help students grasp the mathematics concepts.
Items 1.2.1: Apply effective teaching strategies reflecting different contents and features.
1.2.2: Apply proper teaching strategies related to students' learning ability and understanding.

3. Lead students into some deep thinking.
Items: 1.3.1: Give proper questions to students leading to clear thinking.
1.3.2: Use related materials to help them do positive thinking.
1.3.3: Offer thinking process to help students do mathematics creation.

4. Explain students' misconception at right time.
Items 1.4.1: Give clear explanations when students misunderstand.
1.4.2: Clarify the confusing ideas for students.

5. Apply teaching activities effectively.
Items 1.5.1: Arrange the procedure and pace for each class.
1.5.2: Match the teaching situation and arrange the order of activities.
1.5.3: Give a complete conclusion when a topic has been completely taught.

6. Evaluate teaching assessment in each period to make a necessary change to meet the learner's ability.
Items 1.6.1: Understand students' backgrounds through proper evaluation before teaching.
1.6.2: Give a quiz to test learner's understanding during the teaching proceedings.
1.6.3: Give a complete exam at the end of a finished lesson.

7. Be able to express ideas clearly.
Items 1.7.1: Use the right terms indicating the concepts of mathematics.
1.7.2: Give lectures in a logical order.
1.7.3: Teach lessons with normal speed and voice.

8. Have good board-writing skills.
Items 1.8.1: Have ability ot draw correct charts and graphics for teaching purposes.
1.8.2: Be responsible for neat writing.
1.8.3: Arrange board management.

Dimension 2. Material Organization and Presentation

1. Plan proper contents and good organization.
Items 2.1.1: Arrange the proper materials in order to create students' cognition and learning ability.
2.1.2: make a well-organized teaching syllabus.

2. Present lectures effectively.
Items 2.2.1: Instruct contents correctly.
2.2.2: Give handouts to enhance students' understanding.
2.2.3: Apply media and material effectively.

3. Help students understand the connection and application of mathematics.
Items 2.3.1: Help students understand the connection between math concepts.
2.3.2: Stress the connection between math and other disciplines.
2.3.3: Stress the application of math to life.

4. Arrange proper assignments and evaluation.
Items 2.4.1: Arrange proper assignments according to content and students' learning.
2.4.2: Evaluate assignments properly according to content and students' learning.

Dimension 3. Management of the Learning Environment

1. Creat a positive learning environment.
Items 3.1.1: Arrange best situations for students' learning.
3.1.2: Decorate the teaching environment to reflect different topics.

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3.1.3: Stimulate student's learning motivation with proper teaching skills.
3.1.4: Build student's learning confidence with proper teaching skills.

2. Build two-way communication between teachers and students.

Items 3.2.1: Encourage students to express their ideas through asking them questions.
3.2.2: Let students participate in teaching activities.
3.2.3: Let students work in pairs and cultivate their discussing abilities.
3.2.4: Give students clear responses from their reflections or feedback.

Dimension 4. Teaching Attitudes

1. Display teaching enthusiasm.

Items 4.1.1: Teach with professional confidence.
4.1.2: Teach with a warm heart.
4.1.3: Teach with enthusiastic attitudes.

2. Self-reflections on teaching method.

Items 4.2.1: Accept students' comments and suggestions.
4.2.2: Improve teaching methods based on the teaching assessment.
4.2.3: Improve teaching methods through self reflective thinking.

Table 2. Assessment Instrument-Teaching Simulation Situation Videotapes

situations	Topics	Situation descriptions	Assessment items
1	ratio	Arouse students' motivation by giving then examples of daily life at the beginning of the lesson	1.2.1, 1.3.1, 1.3.2, 3.1.3 1.7.1
2	a simple equation	Have two students go up to the board and solve the problem in two different ways	1.3.3, 2.2.1, 2.3.1
3	parallel lines	Have students do difficult and challenging exercises	1.5.2, 3.2.2, 4.2.2
4	geometric series	Have students raise their hands when teaching the concept of a simple and compound interest	1.4.1, 1.7.1, 2.3.2, 3.2.4, 4.1.1
5	square root	Have two students go up to the board and do the exercise right after the concept is completely taught	1.3.1, 1.4.1, 1.4.2
6	linear function	Teach the concepts of linear function with daily examples	1.2.1, 2.3.3, 3.1.1, 1.2.1

VI. Application

The results of the study have the following advantages: the assessment approaches and the instrument can be applied not only to confer a certificate on a qualified mathematics teachers, and to give feedback to the educational courses for student teachers, but also to employ or dismiss teachers, to set guidlines for professional development, and to establish criteria for the assessment of instructional competencies.

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國民中學數學科教師教學能力評鑑模式及工具之研究

柳　賢

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摘　要

本研究之主要目的在探究數學科教師教學時所應具備之各項基本能力，設計數學科實習教師檢定之評鑑模式及師資檢定評鑑工具，做爲師資評鑑之參考。

本研究有關教師教學時所應具備的各項基本能力及其教師檢定模式部分，探實證研究法。綜合數學科教師教學基本能力的相關資料、情境、文獻與意見，以形成研究教學基本能力向度的理論架構，再依教學能力向度及指標，配合不同單元內容編寫各種教學案例，並攝製成影帶，以畫面來呈現實際教學中有關單元教學、師生互動及教室管理等情境，使每位實習教師皆得依畫面的情境執行教學演示，評鑑委員則依其表現及教學基本能力評鑑標準來考評，而達到公平、客觀的評鑑原則。

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Software Based on S-P Chart Analysis and Its Applications

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Abstract

This software system based upon the Student-Problem chart analysis theory can help teachers manage the miscellaneous tasks of educational assessment. Its major functions include:

1. Diagnosing student learning: Teachers can diagnose students who are maladjusted to the learning environment. At the same time, teachers should provide separate learning plan to improve student learning achievement.
2. Diagnosing problem quality: According to diagnostic information and the results of item analysis and distraction analysis, teachers can analyze the quality of a problem. Then, teachers can modify or delete defective problems, and fit good ones into an item bank for future use.
3. The teacher's self-adjustment: Teachers can classify the common misconceptions of the instruction materials and perform a self-adjustment on their instruction design, teaching materials, techniques, and strategies.
4. Managing the student's performance profile: Teachers can manage the S-P chart information of each instruction unit and draw up a performance profile curve of each student. From the performance profile curve and related information, teachers will be able to discover the causes of learning problems. Then, teachers can provide students with necessary guidance or re-instruction.
5. Instructor function: Teachers can learn how to apply this system and S-P chart analysis theory.

Key Words: Student-Problem chart analysis, disparity index, caution index

I. Introduction

Takahiro Sato is a Japanese Education Engineering Professor who has been concerned deeply about the differences of response data obtained from student answers. He invented Student-Problem chart analysis (S-P chart analysis) which can help teachers diagnose the abnormal performances held by students or problems. Later on, many American and Japanese scholars joined the study of S-P chart analysis. Subsequently, they announced new indices, like Harnisch & Linn's (1981) modified caution index, Tatsuoka & Tatsuoka's ICI (Individual Consistency Index, 1982), Tatsuoka & Tatsuoka's SECI (Standardized Extended Caution Index, 1984), and so on. Tatsuoka (1983) invented the rule space theory, which combined S-P chart analysis theory with item response theory, to diagnose the misconceptions held by students. As a result, the S-P chart analysis theory was promoted as one of the modern test theories. Sato (1984) did market research on the evaluation methods used in Japan, and the results showed that S-P chart analysis is an important assessment tool in primary and secondary schools.

The numbered indices used in S-P chart analysis include the disparity index, student caution index (CS), problem caution index (CP), and homogeneity index. These indices can help teachers diagnose student learning conditions, instructive achievement, and problem quality. In addition, teachers are able to use the analyzed S-P chart data to draw up a performance profile curve for each student. Studying the above information, such as the CS, CP, disparity index, performance profile curve, and so on, teachers can provide proper remedial instruction and better guidance for students who need it.

When performing S-P chart analysis, we often execute some repetitive actions, like moving and

125

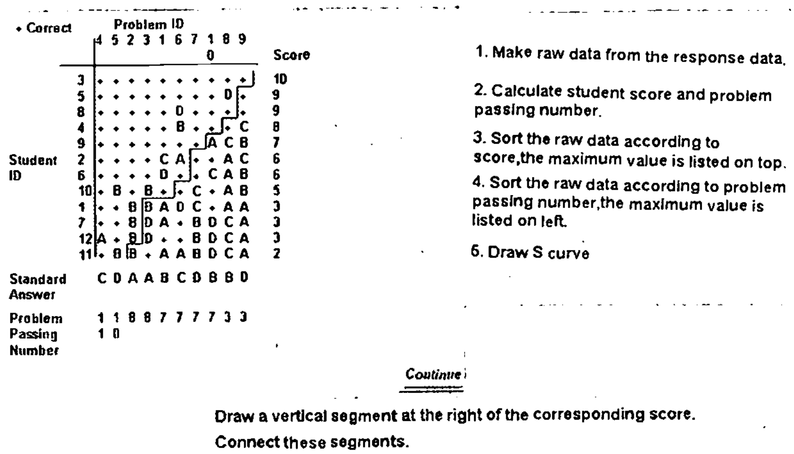

Fig. 1. Explaining the implementation of the S-P chart.

rearranging data. At the same time, the processed data are numbered 1 or 0, or denoted as student response data; therefore, it is very easy to make mistakes in processing. This will reduce the teachers' motivation of using S-P chart analysis as an assessment tool.

The major purpose of this software system is to computerize S-P chart analysis and related application tasks, such as student learning diagnose analysis, problem diagnose analysis, student learning performance profile curves, and so on. Using this software, teachers can reduce the number of miscellaneous tasks involved in educational assessment; hence, he/she can spend more time on guidance and teaching tasks, which can improve student learning effectiveness, teaching quality, and so on.

II. Design

In order to accomplish the above mentioned functions, this software should possess the abilities to build up S-P chart information, calculate the disparity index and caution index, analyze student learning and item quality, analyze student and problem error types, manage student learning performance profiles, and instructor system. The instructor system can help teachers thoroughly learn how to apply the entire S-P chart analysis theory, such as how to build up the raw data file for this system (like Figs. 2 and 3), implement the S-P chart, calculate the various indices, and so on. For example, Fig. 1 shows how to draw the S-curve of the S-P chart. As shown in Fig. 1, the left side shows a data sample, the right side shows the procedures for drawing S-curve.

```
S=43
P=20
ANS=C B A D C B D B D D B B B C B C C A A A
5EA01= C B A D C B D B D D B B B C B C C A A A
5EA05= C B A D C B D B D D B B B C B C D A A A
5EA07= C B A D C B D B D D B B B C B C D A C C
5EA11= C B A D C B D B D D B B A A B D C A C A
5EA12= C B A D C B D B D D B A B A B C C C C D
5EA14= C B A D C B D A D D B B A C B C B A A C
5EA18= C B A B C B D B D D B A B A D C A B A C
5EA19= C B A D D B D D D D B B B C D A C C C C
5EA20= C B A D C B D B D B B B B A B C B A C C
5EA24= C B A B C B C C D D B B B C A C C D C D
5EA25= C B A D C B D C A A B B B D B C A C A A
5EA28= C B A B C B A C D D B B B A B C C B A C
5EA30= C B A D C B B B D D B A C D D C C B D A
5EA32= C B C D C B C B D D B B D A C C C A A C
5EA54= C B A A D B C D D B B B B C B C C A A C
5EB02= C B A D A B C D A D B B B C B C C B A A
5EB03= C B A D A B C B D D B B C A B C C D C C
5EB06= C B A A C B A C D D B A A B B B C A A C
5EB08= C B A D B B B B D D B B B D B B B B C C
5EB09= C B A D A B D C D D B B C C B   B A C C
5EB13= C B A D D B C B D D B B B A B A B B C D
5EB18= C B A D D B A C D D B D B B B A B D C A
5EB23= C B A D C B A B B D B A C D B C B D C C
5EB28= C B A D C B D A D C B A D A A C D B C A
5EC02= C B A D C B A A D B B D A C A A C A D C
5EC06= C B A D C B B A D D B D C A A A C D C A
5EC07= C B B D A B A B D D B B A C B A B D C C
5EC08= C B A D C D A B A D B B B B B C A D C C
5EC10= C B A D A A C B B D B B B B A C B A D A
5EC11= C B A C B B D B D B B B A B C A A B C C
5EC14= C B A D B B C C D A B B C C A C B C D D
5EC23= A B A A C B A C D C B B D C A A B A D D
5EC27= C B A D B B D C D A B D D B C A D D C D
5EC44= C B A D C B B C C B B B B B B A D A A A
5EC48= C B A D B B B C D A B A D A C C C A D D
5EC55= C B A D B A A B A A D C A C D C B B C C
5ED01= C B A B B B A B D C B C D C B A D D C C
5ED02= C D A D B B C D D A B B C A B D B B C C
5ED09= C A A D D B A C D D B A C D C C A C C C
5ED10= A B A D B B B C C B C B C B D C A C C C
5ED13= C D A B B D B D D B C C D C C C D B C C
5ED15= B C B D A C A C B D B C A D A A D B C C
5ED21= B B A D C C B C A B A D A B A B C C C C
```

Fig. 2. The raw data format for general analysis.

```
S=43
P=20
ANS= 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
5EA01= 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
5EA05= 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 D 1 1 1
5EA07= 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 D 1 C C
5EA11= 1 1 1 1 1 1 1 1 1 1 1 1 A A 1 D 1 1 C 1
5EA12= 1 1 1 1 1 1 1 1 1 1 1 A 1 A 1 1 1 C C D
5EA14= 1 1 1 1 1 1 1 A 1 1 1 1 A 1 1 1 B 1 1 C
5EA18= 1 1 1 B 1 1 1 1 1 1 1 A 1 A D 1 A B 1 C
5EA19= 1 1 1 1 D 1 1 D 1 1 1 1 1 1 D A 1 C C C
5EA20= 1 1 1 1 1 1 1 1 1 B 1 1 1 A 1 1 B 1 C C
5EA24= 1 1 1 B 1 1 C C 1 1 1 1 1 1 A 1 1 D C D
5EA25= 1 1 1 1 1 1 1 C A A 1 1 1 D 1 1 A C 1 1
5EA28= 1 1 1 B 1 1 A C 1 1 1 1 1 A 1 1 1 B 1 C
5EA30= 1 1 1 1 1 1 B 1 1 1 1 A C D D 1 1 B D 1
5EA32= 1 1 C 1 1 1 C 1 1 1 1 1 D A C 1 1 1 1 C
5EA54= 1 1 1 A D 1 C D 1 B 1 1 1 1 1 1 1 1 1 C
5EB02= 1 1 1 1 A 1 C D A 1 1 1 1 1 1 1 1 B 1 1
5EB03= 1 1 1 1 A 1 C 1 1 1 1 1 C A 1 1 1 D C C
5EB06= 1 1 1 A 1 1 A C 1 1 1 A A B 1 B 1 1 1 C
5EB08= 1 1 1 1 B 1 B 1 1 1 1 1 1 D 1 B B B C C
5EB09= 1 1 1 1 A 1 1 C 1 1 1 1 C 1 1 E B 1 C C
5EB13= 1 1 1 1 D 1 C 1 1 1 1 1 1 A 1 A B B C D
5EB18= 1 1 1 1 D 1 A C 1 1 1 D 1 B 1 A B D C 1
5EB23= 1 1 1 1 1 1 A 1 B 1 1 A C D 1 1 B D C C
5EB28= 1 1 1 1 1 1 1 A 1 C 1 A D A A 1 D B C 1
5EC02= 1 1 1 1 1 1 A A 1 B 1 D A 1 A A 1 1 D C
5EC06= 1 1 1 1 1 1 B A 1 1 1 D C A A A 1 D C 1
5EC07= 1 1 B 1 A 1 A 1 1 1 1 1 A 1 1 A B D C C
5EC08= 1 1 1 1 1 D A 1 A 1 1 1 1 B 1 1 A D C C
5EC10= 1 1 1 1 A A C 1 B 1 1 1 1 B A 1 B 1 D 1
5EC11= 1 1 1 C B 1 1 1 1 B 1 1 A B C A A B C C
5EC14= 1 1 1 1 B 1 C C 1 A 1 1 C 1 A 1 B C D D
5EC23= A 1 1 A 1 1 A C 1 C 1 1 D 1 A A B 1 D D
5EC27= 1 1 1 1 B 1 1 C 1 A 1 D D B C A D D C D
5EC44= 1 1 1 1 1 1 B C C B 1 1 1 B 1 A D 1 1 1
5EC48= 1 1 1 1 B 1 B C 1 A 1 A D A C 1 1 1 D D
5EC55= 1 1 1 1 B A A 1 A A D C A 1 D 1 B B C C
5ED01= 1 1 1 B B 1 A 1 1 C 1 C D 1 1 A D D C C
5ED02= 1 D 1 1 B 1 C D 1 A 1 1 C A 1 D B B C C
5ED09= 1 A 1 1 D 1 A C 1 1 1 A C D C 1 A C C C
5ED10= A 1 1 1 B 1 B C C B C 1 C B D 1 A C C C
5ED13= 1 D 1 B B D B D 1 B C C D 1 C 1 D B C C
5ED15= B C B 1 A C A C B 1 1 C A D A A D B C C
5ED21= B 1 1 1 1 C B C A B A D A B A B 1 C C C
```

Fig. 3. The raw data format for error statistic analysis; "1" represents a correct answer.

1. The File Format of Raw Data

The input of this system has two formats, one is shown in Fig. 2, which is suitable for general S-P chart analysis, and the other is shown in Fig. 3, which is suitable for error statistics analysis. Their extension names are both RAW. In Figs. 2 and 3, S=43 indicates 43 students, P=20 represents 20 problems, and on the right side of ANS are the standard answers for each problem. As for the remaining information, on the left side of the equal sign (=) is the student code, and on the right side of the equal sign is the response pattern of the student. These files can be written by using the File function of the S-P chart analysis system or word processing software like WordPad.

Set sub-function	Explanation
Model	Change of method of calculating the caution index: Sato or Harnisch model; default model is Sato.
Parameter	Change the critical values of the student caution index, student score ratio, problem caution index, problem ratio, and mastery level; default values are shown in Fig. 5
Item Analysis method	Set up the methods for difficulty analysis and discrimination analysis, as shown in Fig. 6; default methods are the number correct ratio and the point-biserial correlation repectively.
Distraction Analysis method	Set up the groups for distraction analysis, default group is the 1st: 1. high-row group (27%) 2. group (50%) 3. groups (33%) 4. groups (25%) 5. groups (20%)
Printing Direction	Set up the printing direction of printer: vertical (default model) or horizontal.
Message	Display the file name, number of students, number of problems, and disparity index.

Fig. 4. Set function.

2. System Structure

According to the above, the system was designed to have six functions, which are the Set, File, Process, Analysis, Print, and Instructor functions. The Set function (Fig. 4) can help teachers set up the system parameters (Fig. 5), the method of item analysis (Fig. 6), and the method of distraction analysis (Fig. 4). As shown in Fig. 5, a total of six parameters can be set. The first two parameters set the critical value for mastery analysis (lower left corner of Fig. 5). The two parameters in the middle set the critical value for student learning pattern analysis (upper right corner of Fig. 5). The last two parameters set the critical value for problem pattern analysis (lower right corner of Fig. 5).

The Print function can be used to print out the S-P chart analysis information provided by the Analysis function (Fig. 7), as shown in Fig. 9 and Fig. 18. The File function, which is similar to the File and Edit functions in Microsoft Word, is used to save, edit or modify the raw data files required for S-P chart analysis. All raw data files should be handled by the Process function (Fig. 8) before the Analysis function is used.

As shown in Fig. 6, there are two methods for

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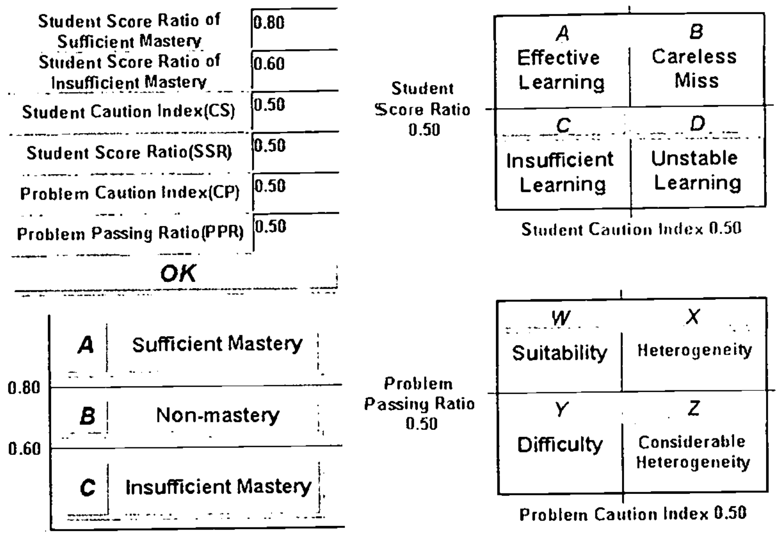

Fig. 5. Parameter function.

Select	Difficulty	Discrimination
○	Number Correct Ratio	Point-Biserial Correlation
○	Number Correct Ratio	High-Low Group
●	High-Low Group	High-low group
○	High-Low Group	Point-Biserial Correlation
○	Number Correct Ratio	Mastery and Nonmastery

High-Low Group

- ● Number(%)
- ○ Score
- ○ Number

High Group 27

Low Group 27

OK

Fig. 6. Item analysis method function.

difficulty analysis: one uses the number correct ratio and the other the high-low group. Discrimination analysis is implemented using three methods: the point-biserial correlation, the high-low group, and the mastery and non-mastery. Hence, there are five methods for item analysis, as shown in Fig. 6. For the high-low group approach, the analytic samples can be divided into three types: one uses the percentage of students (represented by Number (%), where the default value is 27%), another the actual score (represented by Score), and the other the actual number of students (represented by Number).

Among the above mentioned various caution indexes, this system uses Sato's C_i (1980) and Harnisch & Linn's modified caution index C_i* to represent the student and problem caution indexes. The C_i* value is between 0 and 1, and C_i* can eliminate the unreasonable influence due to certain extreme student scores. Sato suggests that a standard C_i value is 0.5. If C_i is higher than 0.5, the teacher should pay attention to the corresponding students (or problems). When C_i is higher than 0.75, the teacher should pay more attention to the corresponding students (or problems). Harnisch suggests that a standard C_i* value is 0.3, and the lower the better. When C_i* is greater than 0.3, the teacher should pay attention to the corresponding students (or problems). About the disparity index D*, Sato suggests that a standard D* value is 0.4 for a quiz, and 0.5 for a combination test. If D* is greater than 0.5 for quiz or 0.6 for combination test, teachers need

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Analysis sub-function	Explanation
Raw S-P chart	Display the unprocessed S-P chart data, including the students'
Analyzed S-P chart	Display the analyzed S-P chart information in graph from, as shown in Fig. 9.
Analyzed S-P chart (Quick Display)	Display the analyzed S-P chart analysis information in table form, without the S-curve and P-curve
Student Learning Pattern	Divide the students into four types based on the student caution indexes and student score rations; the student codes are displayed in the corresponding zone, as shown in Fig. 10.
Class Score Analysis	Display the class information, including raw scores, correct rations, percentage ranks, student caution indices, and learning patterns, as shown in Fig. 11.
Problem Pattern	Divide the problems into four types based in the problem caution indices and problem passing ratios; the problem codes are displayed in the corresponding zone, as shown in Fig. 12.
Item Analysis	Diagnose the difficulty and discrimination of the problems, the displayed information includes problem passing number, difficulty, discrimination, problem caution indices, and problem pattern, as shown in Fig. 13.
Distraction Analysis	Diagnose the distraction ability of the problems, as shown in Fig. 14.
Test Summary	Display the summary information of the test, such as the average correct ratio, mean and standard deviation of caution index, disparity index, and Kuder & Richardson 20 reliability.
Student Error Statistics	Display the class error statistics distribution, as shown in Fig. 15.
Problem Error Statistics	Display the problem error statistics distribution, as shown in Fig. 16.
Performance Profile	Manage the student learning performance for all units, as shown in Fig. 18.

Fig. 7. Analysis function.

to perform a self-adjustment on their instruction designs.

III. Results and Discussion

The following discussion based upon examples shown in Figs. 2 and 3 explains applications of the system in educational assessment. The method of calculating the caution index adopts Sato's model, whose default parameters are shown in Fig. 5, that for item analysis adopts the first method shown in Fig. 6 (number correct ratio, point-biserial correlation), and that for distraction analysis adopts high-low group (27%).

Process sub-function	Explanation
Process. RAW	Process the raw data file according to the procedures for S-P chart analysis.
Save .SPC	Save the processed S-P file (extension name is .SPC)
Load .SPC	Reload the processed S-P file (,SPC)

Fig. 8. Process function.

1. S-P Chart Data Analysis

We can use three functions, the Raw S-P chart, Analyzed S-P chart, and Analyzed S-P chart (Quick Display), to analyze the S-P chart data. The Raw S-P chart function displays or prints out the unprocessed S-P chart information, as shown in Figs. 2 and 3, with student scores and problem passing numbers. The Analyzed S-P chart function displays or prints out the completely processed S-P chart information, as shown in Fig. 9. The Analyzed S-P chart (Quick Display) function is similar to the Analyzed S-P chart function, but it lacks the S-curve and P-curve.

As shown in Fig. 9, the correct answer is indicated by + and an incorrect answer is indicated by a student response answer. The solid line is the S-curve (shown as a red line on the screen) and the broken line is the P-curve (shown as a black line on the screen). In the Score column, the student scores were sorted descendent; hence, the student 5EA01 gets the highest score and the student 5ED15 gets the lowest score. In the Problem Passing Number row, the easier problems are rearranged on the left side, and the more difficult problems are on the right side; hence, problem 3 is the easiest problem, and problems 19 and 20 are the most difficult problems. Investigating the rearranged response data, we can find that the correct portion is centered in the upper left zone, and that the incorrect portion is centered in the lower right zone. When the S-curve moves toward the lower right zone, the student average correct ratio becomes greater; that is, the class has better achievement. In the column for the Student Caution Index, some CS values have a * on the right side, which means that the CS value exceeds the critical value, such as those for students 5EB02 and 5EA32. The teacher should pay attention to these students. For those students with the same scores, the student code with lower CS value is listed upper, such as students

Analyzed S-P Chart

Page : 1

File Name = C:\SP\SPWIN\SPWINE\SPWINE1\DEMO.SPC
Student Number = 43 Problem Number = 20 Model = Sato

Student ID \ Problem ID	3	1	2	11	6	4	9	12	10	16	15	5	8	13	17	14	18	7	19	20	Score	Student Caution Index	Learning Pattern
5EA01	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	20	0.00	A
5EA05	+	+	+	+	+	+	+	+	+	+	+	+	+	+	D	+	+	+	+	+	19	0.35	A
5EA07	+	+	+	+	+	+	+	+	+	+	+	+	+	+	D	+	+	+	C	C	17	0.05	A
5EA14	+	+	+	+	+	+	+	+	+	+	+	+	A	A	B	+	+	+	+	C	16	0.26	A
5EA11	+	+	+	+	+	+	+	+	+	D	+	+	+	A	+	A	+	+	C	+	16	0.38	A
5EA12	+	+	+	+	+	+	+	A	+	+	+	+	+	+	+	A	C	+	C	D	15	0.20	A
5EA20	+	+	+	+	+	+	+	+	B	+	+	+	+	+	B	A	+	+	C	C	15	0.22	A
5EB02	+	+	+	+	+	+	A	+	+	+	+	A	D	+	+	+	B	C	+	+	15	0.61 *	B
5EA28	+	+	+	+	+	B	+	+	+	+	+	+	C	+	+	A	B	A	+	C	14	0.38	A
5EA32	C	+	+	+	+	+	+	+	+	+	C	+	+	D	+	A	+	C	+	C	14	0.57 *	B
5EA25	+	+	+	+	+	+	A	+	A	+	+	+	C	+	A	D	C	+	+	+	14	0.62 *	B
5EA54	+	+	+	+	+	A	+	+	B	+	+	D	D	+	+	+	+	C	+	C	14	0.63 *	B
5EB03	+	+	+	+	+	+	+	+	+	+	+	A	+	C	+	A	D	C	C	C	13	0.08	A
5EB09	+	+	+	+	+	+	+	+	+		+	A	C	C	B	+	+	+	C	C	13	0.28	A
5EA30	+	+	+	+	+	+	+	A	+	+	D	+	+	C	+	D	B	B	D	+	13	0.29	A
5EA19	+	+	+	+	+	+	+	+	+	A	D	D	D	+	+	+	C	+	C	C	13	0.33	A
5EA24	+	+	+	+	+	B	+	+	+	+	A	+	C	+	+	+	D	C	C	D	13	0.35	A
5EA18	+	+	+	+	+	B	+	A	+	+	D	+	+	+	A	A	B	+	+	C	13	0.53 *	B
5EC44	+	+	+	+	+	+	C	+	B	A	+	+	C	+	D	B	+	B	+	+	13	0.64 *	B
5EB08	+	+	+	+	+	+	+	+	+	B	+	B	+	+	B	D	B	B	C	C	12	0.12	A
5EB13	+	+	+	+	+	+	+	+	+	A	+	D	+	+	B	A	B	C	C	D	12	0.12	A
5EC08	+	+	+	+	D	+	A	+	+	+	+	+	+	+	A	B	D	A	C	C	12	0.41	A
5EB06	+	+	+	+	+	A	+	A	+	B	+	+	C	A	+	B	+	A	+	C	12	0.53 *	B
5EC10	+	+	+	+	A	+	B	+	+	+	A	A	+	+	B	B	+	C	D	+	12	0.64 *	B
5EB23	+	+	+	+	+	+	B	A	+	+	+	+	+	C	B	D	D	A	C	C	11	0.21	A
5EB18	+	+	+	+	+	+	+	D	+	A	+	D	C	+	B	B	D	A	C	+	11	0.26	A
5EC06	+	+	+	+	+	+	+	D	+	A	A	+	A	C	+	A	D	B	C	+	11	0.30	A
5EB28	+	+	+	+	+	+	+	A	C	+	A	+	A	D	D	A	B	+	C	+	11	0.33	A
5EC07	B	+	+	+	+	+	+	+	+	A	+	A	+	A	B	+	D	A	C	C	11	0.36	A
5EC02	+	+	+	+	+	+	+	D	B	A	A	+	A	A	+	+	+	A	D	C	11	0.37	A
5EC14	+	+	+	+	+	+	+	+	A	+	A	B	C	C	B	+	C	C	D	D	10	0.12	C
5EC48	+	+	+	+	+	+	+	A	A	+	C	B	C	D	+	A	+	B	D	D	10	0.24	C
5EC11	+	+	+	+	+	C	+	+	B	A	C	B	+	A	A	B	B	+	C	C	9	0.31	C
5ED01	+	+	+	+	+	B	+	C	C	A	+	B	+	D	D	+	D	A	C	C	9	0.32	C
5EC23	+	A	+	+	+	A	+	+	C	A	A	+	C	D	B	+	+	A	D	D	9	0.53 *	D
5EC27	+	+	+	+	+	+	+	D	A	A	C	B	C	D	D	B	D	+	C	D	8	0.14	C
5ED09	+	+	A	+	+	+	+	A	+	+	C	D	C	C	A	D	C	A	C	C	8	0.16	C
5ED02	+	+	D	+	+	+	+	+	A	D	+	B	D	C	B	A	B	C	C	C	8	0.19	C
5EC55	+	+	+	D	A	+	A	C	A	+	D	B	+	A	B	+	B	A	C	C	7	0.58 *	D
5ED10	+	A	+	C	+	+	C	+	B	+	D	B	C	C	A	B	C	B	C	C	6	0.35	C
5ED13	+	+	D	C	D	B	+	C	B	+	C	B	D	D	D	+	B	B	C	C	5	0.60 *	D
5ED21	+	B	+	A	C	+	A	D	B	B	A	+	C	A	+	B	C	B	C	C	5	0.63 *	D
5ED15	B	B	C	+	C	+	B	C	+	A	A	A	C	A	D	D	B	A	C	C	3	0.45	C
Standard Answer	A	C	B	B	B	D	D	B	D	C	B	C	B	B	C	C	A	D	A	A			
Problem Passing Number	40	39	39	39	37	34	33	26	26	25	23	22	19	18	16	16	15	14	11	11			
Problem Pattern	W	W	W	W	W	W	W	W	W	W	W	W	Y	Y	Y	Y	Y	Y	Y	Y			
Problem Caution Index	0.03	0.01	0.01	0.01	0.02	0.09	0.07	0.06	0.07	0.10	0.05	0.07	0.11	0.05	0.14	0.17	0.18	0.08	0.07	0.12			

Disparity Coefficient = 0.46

Fig. 9. Printout of analyzed S-P chart function.

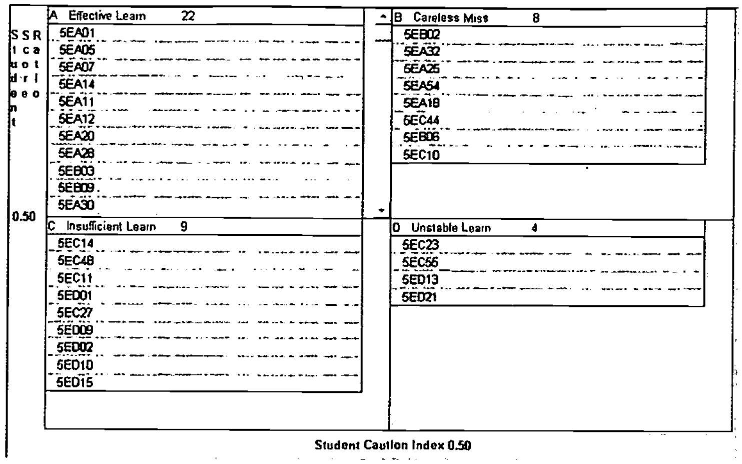

Fig. 10. Student learning pattern function.

Student ID	Score	Ratio(%)	Rank	CS	Learning Pattern	
5EA01	20	100.00	99	0.00	A	Effective Learn
5EA05	19	95.00	97	0.35	A	Effective Learn
5EA07	17	85.00	94	0.05	A	Effective Learn
5EA14	16	80.00	91	0.26	A	Effective Learn
5EA11	16	80.00	91	0.38	A	Effective Learn
5EA12	15	75.00	85	0.20	A	Effective Learn
5EA20	15	75.00	85	0.22	A	Effective Learn
5EB02	15	75.00	85	0.61	B	Careless Miss
5EA28	14	70.00	77	0.38	A	Effective Learn
5EA32	14	70.00	77	0.57	B	Careless Miss
5EA25	14	70.00	77	0.62	B	Careless Miss
5EA54	14	70.00	77	0.63	B	Careless Miss
5EB03	13	65.00	64	0.08	A	Effective Learn
5EB09	13	65.00	64	0.28	A	Effective Learn
5EA30	13	65.00	64	0.29	A	Effective Learn
5EA19	13	65.00	64	0.33	A	Effective Learn
5EA24	13	65.00	64	0.35	A	Effective Learn
5EA18	13	65.00	64	0.53	B	Careless Miss
5EC44	13	65.00	64	0.64	B	Careless Miss

	Score	Ratio(%)	CS
Mean	11.70	58.49	0.35
Standard Deviation	3.56	17.80	0.18

	A	B
0.50	C	D
	0.50	

Fig. 11. Class score analysis function.

5EA14 and 5EA11. Similarly, for those problems with the same problem passing number, the problem code with lower CP value is listed left, such as problems 1, 11, and 2.

Using the information from Fig. 9, the teacher can directly analyze the tasks of educational assessment. For example, the scores of students 5EB08, 5EB13, 5EC08, 5EB06, and 5EC10 are all 12, but the last three students' CS values are much higher than those of the first two students, which means that their answers are abnormal. Exhaustive study of Fig. 9 reveals that the three students have answered wrongly the easier problems, like problems 6, 4, 9, and 12. This is especially significant for student 5EC10; his CS value is 0.64, which already exceeds the critical value, 0.5. For those students who have abnormal performance, the teacher should provide individual and proper guidance to determine the reasons for learning difficulty and then provide them with remedial material, which will lead to better achievement. The disparity index D^* is 0.46 (on the lower right side), and it means that the instruction for this teaching unit is effective.

2. Diagnosing Student Learning

We can use two functions, the Student Learning Pattern and Class Score analysis, to diagnose student learning. Based on the student caution index and student score ratio, the Student Learning Pattern function divides the students into 4 categories (A, B, C, D) and displays the student codes in the corresponding

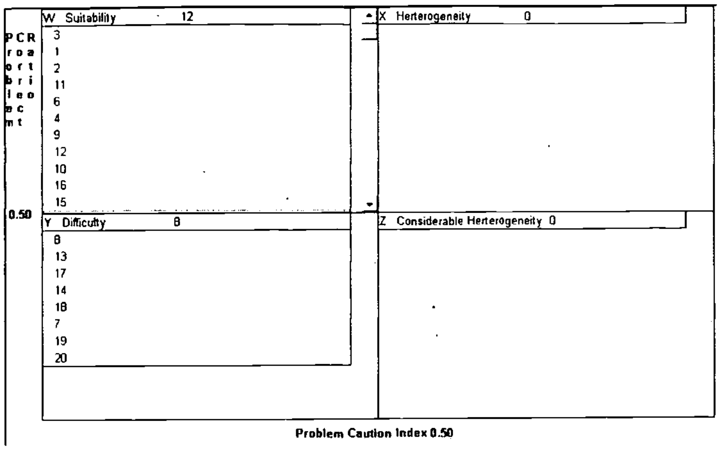

Fig. 12. Problem pattern function.

zone, as shown in Fig. 10. The classified standard is shown in Fig. 5.

In Fig. 10, twenty-two students (occupying 51.16%) are in the Effective Learn zone, so their learning behavior is very stable and their achievement in class is good. Nine students (occupying 20.93%) are in the Insufficient Learn zone; their basic knowledge is poor and they do not study hard enough, so the teacher should provide proper remedial instruction and guidance for them. Eight students (occupying 18.6%) are in the Careless Miss zone. Their learning is slightly uneven, and they answer problems carelessly; hence, if they pay attention to their learning, their achievement will become better. Four students (occupying 9.3%) are in the Unstable Learning zone. These students have no interest in studying and their learning is very uneven; therefore, they usually answer problems by guessing, and their answers are sometimes unexpected. The teacher can use the mouse to click on any student code, and the system will display the corresponding student information (score, score ratio, and student caution index).

The Class Score Analysis function supplies the teacher with all of the class information, which includes raw scores, score ratios, percentage ranks, student caution indexes, and learning patterns. As shown in Fig. 11, the average score for this class is 11.70, and the average correct ratio is 58.49%.

3. Diagnosing Problem Quality

We can use four functions, the Problem Pattern, Item Analysis, Distraction Analysis and Test Summary, to diagnose problem quality. The Problem Pattern function uses problem caution index and problem passing ratio to diagnose problem quality. It divides the problems into 4 types (W, X, Y, Z) and displays the problem codes in the corresponding zone, as shown in Fig. 12. The classified standard is shown in Fig. 5. Similarly, the teacher can use the mouse to click on any problem code, and the system will display the corresponding problem information (problem passing number, problem correct ratio, and problem caution index).

As shown in Fig. 12, twelve problems (occupying 60%) which are classified in the Suitability zone are quite good and can be used to distinguish the degrades of students. Eight problems (occupying 40%) are in the Difficulty zone. The problem caution index is smaller than the critical value (0.5), but the problem passing ratio is also smaller than the critical value (50%); hence, these problems are suitable for the students with better achievement and are difficult for students with poor performance. The problems, which are in the Heterogeneity zone, contain a few heterogeneous factors. Though the problem caution index is greater than the critical value, the problem passing ratio is also greater than the critical value; hence, these problems should be modified slightly. The problems, which are in the Considerable Heterogeneity zone, contain many heterogeneous factors. The problem caution index is high, and the problem passing ratio is low, which means that their properties are much different from those of other problems; therefore, these problems should be deleted or modified greatly.

Based on the item analysis method shown in Fig. 6, Item Analysis function performs difficulty and discrimination analysis of test problems. The displayed information includes the problem passing number, difficulty, discrimination, problem caution

Problem ID	Passing Number	Difficulty	Discrimination	CP	Problem Pattern
3	40	0.93	0.18	0.03	W Suitablity
1	39	0.91	0.53	0.01	W Suitablity
2	39	0.91	0.51	0.01	W Suitablity
11	39	0.91	0.53	0.01	W Suitablity
6	37	0.86	0.49	0.02	W Suitablity
4	34	0.79	0.12	0.09	W Suitablity
9	33	0.77	0.29	0.07	W Suitablity
12	26	0.60	0.48	0.06	W Suitablity
10	26	0.60	0.47	0.07	W Suitablity
16	25	0.58	0.33	0.10	W Suitablity
15	23	0.53	0.56	0.05	W Suitablity
5	22	0.51	0.48	0.07	W Suitablity
8	19	0.44	0.36	0.11	Y Difficulty
13	18	0.42	0.58	0.05	Y Difficulty
17	16	0.37	0.30	0.14	Y Difficulty
14	16	0.37	0.20	0.17	Y Difficulty
18	15	0.35	0.49	0.08	Y Difficulty
7	14	0.33	0.49	0.08	Y Difficulty
19	11	0.26	0.53	0.07	Y Difficulty
Moon	25.15	0.58	0.42	0.07	
Standard Deviation	9.94	0.24	0.14	4.26	

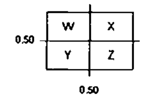

Fig. 13. Item analysis function.

Problem ID	Group	Alternative					
		A	B	C	D	E	Empty
1	High 12	0	0	12	0	0	0
	Low 12	2	2	8	0	0	0

Standard Answer	**C**
Difficulty	**0.91**
Discrimination	**0.53**
Problem Caution Index	**0.01**
Problem Correct Ratio	**90.70**
Problem Pattern	**Suitablity**

Fig. 14. Distraction analysis function.

index, and problem pattern, as shown in Fig. 13. The average difficulty is 0.58, which is close to the value of 0.5 suggested by scholars. Moreover, based on the discrimination standard of Ebel (1991), problems 3 and 4 must be modified greatly or deleted, and the rest are all within a reasonable range. The problem caution indices are all within the critical value range. Therefore, the test problems are proved to be suitable and excellent.

The problems with good distraction capability will reduce the probability of guessing. The teacher can use the Distraction Analysis function to analyze the distraction capability of incorrect alternatives for each problem. As shown in Fig. 14, the incorrect alternatives A, B, D, and E are not chosen by the high scoring group, and the incorrect alternatives D and E also are not chosen by the low scoring group. This shows that the distraction capability of problem 1 is poor. According to the information shown in Fig. 13, problem 1 is quite good; however, if we modify carefully the incorrect alternatives A, B, D, and E, problem 1 will be even better.

The Test summary shows a summary of the test results. The displayed information includes the average correct ratio, the mean and standard deviation of the caution index, the disparity index, and the test reliability. In this system, test reliability adopts KR_{20} reliability (Kuder & Richardson formula KR_{20} reliability). In Fig. 9, the KR_{20} reliability is 0.74.

4. Diagnosing Student and Problem Error Types

We can use two functions, the Student Error Statistics and Problem Error Statistics, to diagnose student and problem error types. Teachers, after marking test problems, can use the Student Error Statistics function to categorize the student error patterns. For example, the error patterns can be divided into 5 types represented by codes: calculation errors (represented by A), partly errors (represented by B), misconception errors (represented by C), missing information errors (represented by D), and no answer errors (represented by E). They can be made

Student ID	Score	CS	A	B	C	D	E
5EA01	20	0.00	0	0	0	0	0
5EA05	19	0.35	0	0	0	1	0
5EA07	17	0.05	0	0	2	1	0
5EA14	16	0.26	2	1	1	0	0
5EA11	16	0.38	2	0	1	1	0
5EA12	15	0.20	2	0	2	1	0
5EA20	15	0.22	1	2	2	0	0
5EB02	15	0.61	2	1	1	1	0
5EA28	14	0.38	2	2	2	0	0
5EA32	14	0.57	1	0	4	1	0
5EA25	14	0.62	3	0	2	1	0
5EA54	14	0.63	1	1	2	2	0
5EB03	13	0.08	2	0	4	1	0
5EB09	13	0.28	1	1	4	0	1
5EA30	13	0.29	1	2	1	3	0
5EA19	13	0.33	1	0	3	3	0
5EA24	13	0.35	1	1	3	2	0
5EA18	13	0.53	3	2	1	1	0
5EC44	13	0.64	1	3	2	1	0
5EB08	12	0.12	0	5	2	1	0
5EB13	12	0.12	2	2	2	2	0
5EC08	12	0.41	3	1	2	2	0
5EB06	12	0.53	4	2	2	0	0

Student Error Pattern	A	B	C	D	E
Total	98	75	113	70	1

Fig. 15. Student error statistics function.

Problem ID	Passing Number	CP	A	B	C	D	E
1	39	0.08	2	2	0	0	0
2	39	0.09	1	0	1	2	0
3	40	0.35	0	2	1	0	0
4	34	0.44	3	5	1	0	0
5	22	0.19	6	10	0	5	0
6	37	0.14	2	0	2	2	0
7	14	0.15	12	8	9	0	0
8	19	0.26	4	0	15	5	0
9	33	0.32	5	3	2	0	0
10	26	0.20	6	8	3	0	0
11	39	0.08	1	0	2	1	0
12	26	0.19	8	0	4	5	0
13	18	0.11	9	0	9	7	0
14	16	0.35	12	9	0	6	0
15	23	0.14	9	0	6	5	0
16	25	0.30	12	3	0	2	1
17	16	0.29	6	13	0	8	0
18	15	0.16	0	12	7	9	0
19	11	0.11	0	0	26	6	0
20	11	0.20	0	0	25	7	0

Problem Error Statistics	A	B	C	D	E
Total	98	75	113	70	1

Fig. 16. Problem error statistics function.

into a raw file, as shown in Fig. 3. After executing the Student Error Statistics function, we can obtain results like those in Fig. 15. From the chart, the teacher can understand the distribution of the student error patterns. For the class, C (misconception error) is the most common error pattern. The teacher should prepare more useful materials that can help students to establish correct conceptions. Among the individual cases, the worst error pattern of student 5EB08 is B, which shows that student 5EB08 has poor understanding of this learning unit, so the teacher should provide individual guidance for him. This system allows 15 different error pattern codes (A to O).

After executing the Problem Error Statistics function, we can obtain results like those shown in Fig. 16. Therefore, the teacher can understand the distribution of problem error patterns. For example, C (misconception error) is also the worst error pattern; hence, teaching materials related to error pattern C should be taught again, especially the materials tested by problems 20, 19, 7 and 8.

5. Managing Student Performance Profiles

We can use the Performance Profile function to manage the student learning performances for all of the teaching activities. According to the mastery theory, students who can not reach the scheduled mastery level for an instruction unit are not at all ready to study the next unit. In this system, each unit may include three tests, as shown in Fig. 17. For example, Unit 1 (the subject is Basic Electricity and the unit is Circuit Element) has two S-P data files: element1.spc and element2.spc. After each test, remedial in-

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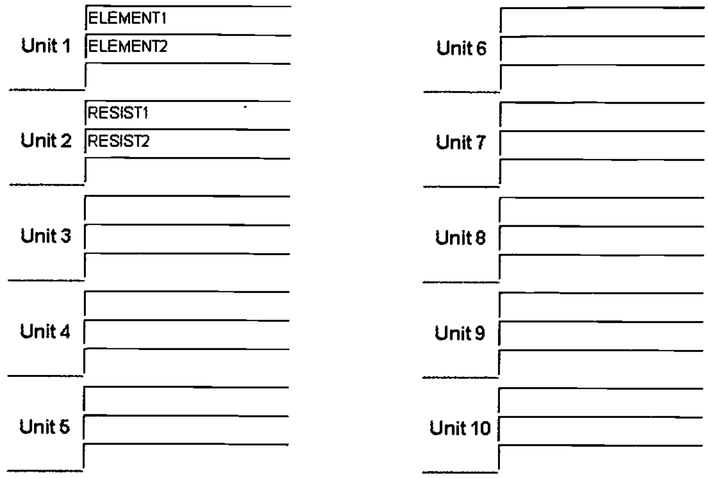


Fig. 17. Inputs of performance profile.

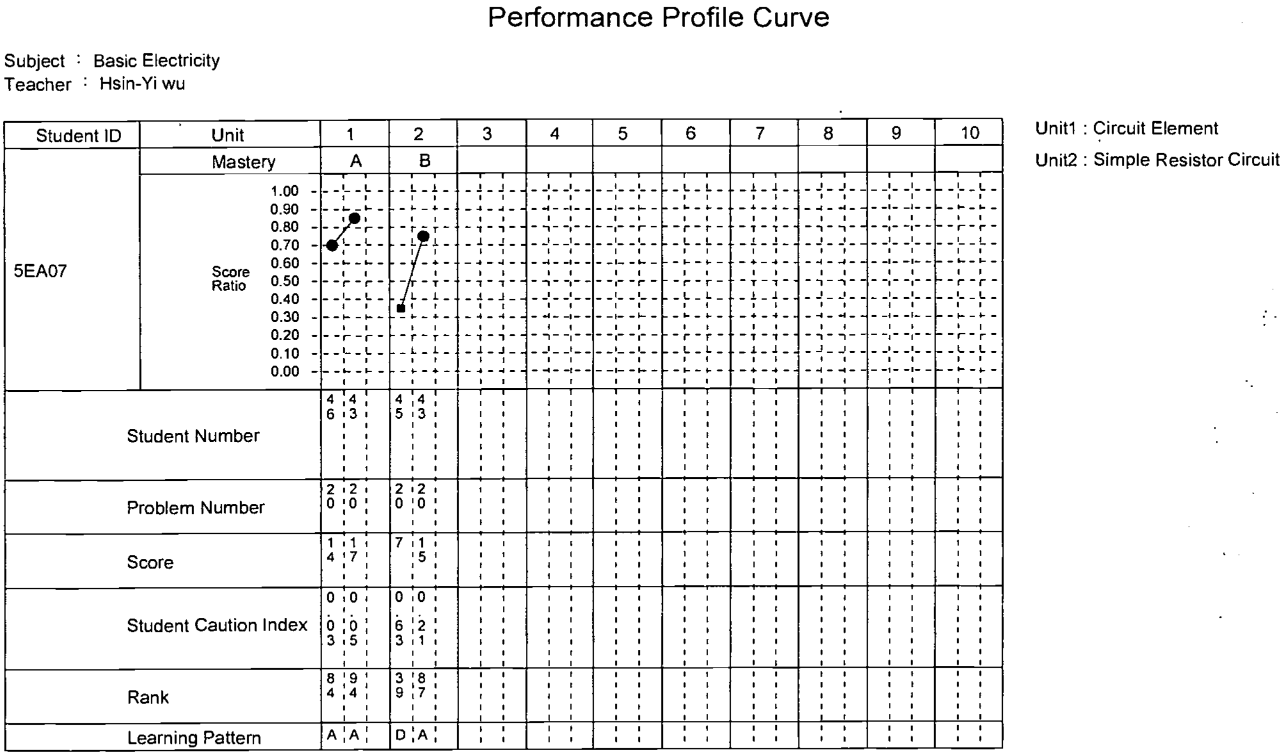
struction is given to the students whose achievement levels do not reach the scheduled level assigned by the Set function. As shown in Fig. 5, if a student's score ratio was more than or equal to 80%, the system assigns the student to mastery level A. At the same time, the mastery level of each instruction unit is assigned to the highest grade among the three tests. The extension name of a performance profile file is ".PRF".

Fig. 18 shows the learning performance profile curve of student 5EA07. The information includes the raw score, caution index, percentage rank, and learning pattern. If the caution index is smaller than or equal to the critical value, the corresponding curve is denoted by a round dot (green on the screen), otherwise, the corresponding curves are denoted by a square dot (red on the screen). Student 5EA07, on the first test (element1.spc) for Unit 1, did not reach the scheduled level A. He received remedial instruction on Unit 1 and then reached the scheduled level A on the 2nd test (element2.spc); therefore, he can study the material in Unit 2 (Simple Resistor Circuit). Similarly, student 5EA07 did not reach the scheduled level A on the first test (resist1.spc) for Unit 2. Notably, his caution index (0.63) is greater than the critical value (0.5); his learning pattern is in the D zone and is categorized to unstable group. He seems to have studied Unit 2 carelessly. Hence, the teacher needed to pay more attention to him. Though the teacher taught him again, he still did not reach the scheduled level A on the 2nd test.

IV. Conclusion

This software system is executed under Windows. Besides the standard S-P chart analysis function, it also possesses student and problem error pattern analysis, learning performance profile, and instructor functions. As previously mentioned, the system includes the following functions:

1. Diagnosing student learning: Teachers can detect students who are maladjusted to the learning environment, according to diagnostic information, such as S-P chart analysis data, student caution indexes, student learning patterns, performance profile curves, and so on. At the same time, teachers should provide separate learning plan to improve student learning achievement, such as remedial instruction based on student required material, proper guidance, and so on.
2. Diagnosing problem quality: According to diagnostic information, such as S-P chart analysis data, problem caution indices, problem patterns, and the results of item analysis and distraction analysis, teachers can analyze the quality of a problem. Then, teachers can modify or delete defective problems, and fit good ones into an item bank for future use.
3. The teacher's self-adjustment: Using diagnostic information, such as student or problem error statistics, disparity indices, and so on, teachers can classify the common misconceptions of the instruction materials and perform a self-criticism on their instruction design, including teaching materials, techniques, and strategies. That is a good way to improve teaching skills and teaching effectiveness.
4. Managing the student's performance profile: Throughout the teaching activities, teachers can manage the S-P chart information of each instruction unit and draw up a performance profile curve



Mastery => A:Sufficient Mastery B:Nonmastery C:Insufficient Mastery
Learning Pattern => A:Effective Learning B:Careless Miss C:Insufficient Learning D:Unstable Learning
Solided Circle => Student Caution Index is less than or equal to critical value
Solided Square => Student Caution Index is greater than critical value

Fig. 18. Printout of performance profile function.

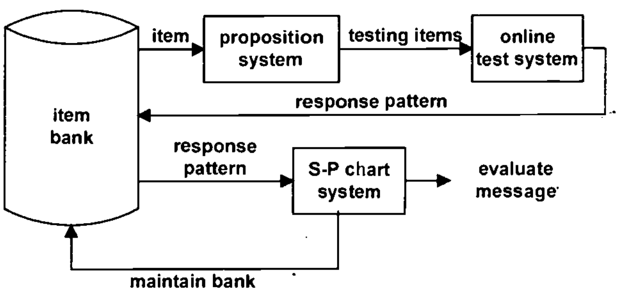


Fig. 19. Application of S-P chart on the Internet.

of each student. From the performance profile curve and related information, teachers will be able to discover the causes of learning problems. Then, teachers can provide students with necessary guidance or re-instruction. Moreover, teachers can frequently show the learning performance profile curve to parents, who can grasp the child's study progress. This is a good way to establish good bilateral relations between teachers and parents.

5. Instructor function: Teachers can learn how to apply the entire S-P chart analysis theory, such as how to build up the raw data file, implement the S-P chart, calculate the index, and so on. Hence, this function can promote the usage of this system.

When using this system, teachers can execute the File function or use WordPad software to implement the raw file (shown in Figs. 2 or 3) based on student response patterns, manipulate the raw file using the Process function, and then diagnose the processed data using the Analysis function. This system could also be worked on the Internet (as shown in Fig. 19). Using the computer item bank system, students can take tests on the Internet and the computer will collect the students' response data. At the end of the test, the computer will convert the data into a raw file, which can be processed by the S-P chart software system. This will increase the convenience and accuracy of this system, and provide immediately information for each student. The various information related to item analysis and problem caution indices can be used to maintain the item bank.

This system software (spwine.rar for English, spwinc.rar for Chinese) could be downloaded from the following IP address:

ftp://140.128.43.1/

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學生問題圖表分析軟體與其應用

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摘 要

本系統可作爲教師從事教學評量時之有效工具，其主要原理爲 S-P 圖表分析理論；本系統的主要功能有：

1. 學生學習診斷分析功能：教師可以發現學習適應不佳的學生，並依學生個別需求實施適當的輔導與補救教學，以提升其學習成效。
2. 試題診斷分析功能：教師可以依據 S-P 圖表分析資料、試題分析與誘答力分析等資料，分析試題的品質，並修改有缺失的試題，優良的試題可納入題庫以供日後命題使用。
3. 教師自我檢討教學得失：教師可以從錯誤類型分析資料上，自我檢討教學設計、教材、策略、技巧等，以改進教學。
4. 學生學習遷移曲線：教師可以依據 S-P 圖表分析資料，記錄每位學生在各個教學單元中的學習變動情形；從曲線的變動與各項資料，教師可以了解每位學生學習困難的原因，進行輔導與補救。
5. 教導系統功能：可以使教師瞭解本系統的使用與 S-P 圖表分析理論。

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Reform of Science Education in Taiwan: Contexts, Opportunities, and Concerns

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Abstract

The 1990s have been characterized by widespread discussions about the need for reform in science education. Concurrent with international efforts to reform science education, Taiwan has properly embarked on its own efforts to change the nature of science education. This paper comments on these efforts from the perspectives of two international visitors. It portrays science education reform in Taiwan in the context of global changes that are occurring throughout much of the world and in the context of institutional changes occurring within Taiwan. The paper attempts to elucidate unique assets, problems, and opportunities facing science education reform in Taiwan. The need to incorporate special attention to Taiwan's rich regional resources, local technologies and technology tools, Chinese contributions to technology and to perceptions of the natural world, strength in vocational education, and cultural traditions is briefly examined. The paper also briefly discusses some concerns that may need to be examined such as the role of tests in schools and the society. Some relevant issues are raised regarding science teacher education, teacher evaluation, and teacher engagement in school policy making. Finally, the need to develop standards in science education and to incorporate local resources and examples that are especially relevant to Taiwanese needs, realities, and culture is discussed.

Key Words: science education reform, contexts, opportunities, concerns

I. Introduction

The authors of this paper have been privileged to visit Taiwan several times in the past few years in the roles of conference participants and consultants. We have also been privileged to have had opportunities to benefit from perceptions of international students and colleagues not native to our own country who have helped us to gain a more detached, external perspective of science education and reform in the USA. During this time, we have had the opportunity to observe science teaching and learning in Taiwan as *outsiders*. Since we are not highly experienced in the culture, we can be only partially aware of the many intricacies of schooling and of reform efforts in a culture that is very different from our own. We do "wear the lenses" of science education reform in the USA and other international locations, and our experiences influence our perceptions of what we have observed during our visits in Taiwan. Our qualitative research experiences enable us to know that an *outsider's* view can sometimes identify potentially important factors often overlooked by those deeply engaged within the dynamics of a situation. In a sense, we have been semi-participant observers of the science education reforms in Taiwan, and we hope our perceptions may be of value to our colleagues in Taiwan.

The 1990s have been characterized by widespread discussions about the need for reform in science education in many countries. We hope that the current reform effort will turn out to be more durable than previous efforts as attention to reform appears to be gaining some strength rather than waning in recent years. In addition, organizations in some nations such as the American Association for the Advancement of Science (AAAS) and the National Research Council (NRC) in the USA, have been strong advocates and supporters of reform. (American Association for the Advancement of Science, 1993, & National Research Council, 1996.) In addition, the timeliness of the recent Third International Mathematics and Science Study (TIMSS) has offered a rationale and support for reform needed in many countries. (Baker, 1997) However, regardless of the rationale, the resolve for reform of science education in many countries including the USA appears to remain alive and well at present.

Concurrent with international efforts to reform Science Education, Taiwan has properly embarked on its own efforts to change the nature of science education. Naturally, there should be similarities and differences between the visions Taiwan has for its science education reform and the visions promoted elsewhere.

II. The Global Change Context

This wave of reform in education generally and in science education more specifically is occurring within a world in which significant and dynamic changes are occurring. The world is increasingly becoming a "global village" in which actions in one part of the world exert powerful influences on other parts of the world. Modes and speed of travel and communication have changed dramatically in the last half of the twentieth century. Taiwan has a unique role to play in that context, and the educational reform underway in Taiwan is strongly influenced by reforms that have been initiated in other parts of the world, sometimes in very different cultural settings. Just one example of the significant changes occurring beyond the world of educational reform is the changing boundaries and alliances between nations. Throughout the history of nations, walls have been going up and coming down, but in the past decade, the rate of change of those boundaries and alliances seems to have increased substantially.

The changes that have occurred in the People's Republic of China and Hong Kong, North and South Korea, Eastern and Western Europe, Russia and the former Soviet Union, South Africa, Portugal, and the Middle East offer some powerful examples. These changes in political boundaries have been accompanied by challenging corollary forces that have included movements toward:

1. Democratization
2. More equitable engagement of communities and individuals
3. Exponential growth in science and technology
4. Alternative values
5. Redistribution of wealth

III. The Context for Change in Taiwan

Concurrent with the powerful changes visible in the international context, significant changes are also occurring within Taiwan. These forces are difficult, if not impossible, to avert, and they provide challenges and opportunities for people in the science education community. The changes and challenges developing in Taiwan that are visible to us include:

1. Increased local control of institutions and curricula
2. Increased local responsibility for budgets and decision-making
3. Increased empowerment of local people
4. Changes in the governance and funding of educational institutions and teacher preparation
5. Changes in the preparation, evaluation, and licensure of teachers
6. Challenges to traditional, cultural values

IV. The Science Education Reform Context

Within the last decade, the reform of science education has become a concern in many parts of the world. Numerous reform documents have been developed, principally within individual countries. Two of the most prominent ones in the USA are the National Science Education Standards (National Research Council, 1996) and the Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993). Although there are differences among these and other reform documents, there is a common core of contemporary beliefs or visions regarding science education that has influenced the development of the current reform documents. It is also important to note that while the United States is a pluralistic country and while the documents had input from a wide array of sources in science and education, these documents were developed within a cultural setting in the West that is quite different from the settings for education in many parts of the world. The beliefs or visions associated with contemporary philosophical and cognitive ideas including:

1. Constructivism
2. The nature of science
3. Interdisciplinary integration
4. Collaborative inquiry & problem solving
5. Critical thinking
6. Students' understandings, interests, and perceived relevance
7. Authentic assessment

Constructivism is a term now widely used by many in the science education community to refer to an epistemology contending that students construct ideas about the world through their interactions with that world. There is a reality, but we can not come to know it in any definitive manner because all our knowledge is a construction in our minds that is based upon the knowledge we bring to a problem from earlier experiences. We never come to know reality directly, but rather we construct our understanding of it in our minds. The science teacher is expected to use the constructivist view by providing students with opportunities to develop or "construct" the desired scientific understandings. The current constructivist view is that if students develop understandings other than those of the scientific community, their fundamental concepts are likely to change very little if the teacher simply tells the students they are *wrong*. (Telling them they are wrong often results in changes in the words or the algorithms students use, but it often does not result in the conceptual change the teacher had desired.) To enhance the probability of conceptual growth, the teacher should place the students in situations that enable them to question prior beliefs and understandings with access to ideas of the contemporary science community in order to construct new understandings. The reform documents also state that, within a context of a constructivist instructional environment, the science teacher should stress students' acquisition of an adequate understanding of the nature of science and of science as inquiry. In short, students are expected to be able to perform authentic scientific inquiries as well as to understand inquiry. These goals incorporate both process and product in their instructional orientation.

The current reforms take the position that the best way to promote student understanding of the nature of science and science as inquiry is through an instructional approach that has an inquiry orientation. Students are allowed to pose scientific questions for themselves, develop procedures for answering these questions, collect and interpret data, and come to conclusions regarding their original questions. It is further believed that such an approach will help students develop problem solving and critical thinking skills within an environment that carefully considers students' interests. As students investigate problems relevant to their daily lives it will also become clear that people have arbitrarily separated the various knowledge *disciplines* and that the solutions to *real world* problems involve the application and interaction of many academic disciplines. Understanding and resolving problems involves interdisciplinary knowledge and effort. Finally, the current reforms advocate that assessment of student outcomes must be *authentic*. These ideas and constructivist teaching strategies may work for some teachers and students in the West. Will they be effective in a Taiwanese cultural setting? Good science education research should inform the response to this question. Conventional paper and pencil tests seldom examine practical skills and deep conceptual understanding. Authentic assessment examines a student's ability to conceptualize and to complete scientific investigations as opposed to simply offering a numeric solution or identifying a scientific idea or explanation by responding to multiple choice questions.

The several current reform documents have a view of science teacher education that varies considerably from traditional approaches. Teacher education is viewed as a life-long endeavor that is not artificially delineated into phases of preservice and inservice education. Teachers are viewed as continually developing their skills and knowledge throughout their careers. Consequently, professional development activities are viewed as opportunities that must be consistent with teachers' developmental needs. The same professional development activities are not equally appropriate for all. The teacher is viewed as an informed decision-maker who consistently reflects on instruction in an effort to improve subsequent instructional activities for students. Important ideas about the interaction between knowledge of subject matter and knowledge of pedagogy is articulated in relatively new constructs such as *pedagogical content knowledge*. There is also a need for attending to the balance between theory and practice in the practice of science teaching as well as in the practice of science.

V. The Context for Science Education Reform in Taiwan

In recent years, Taiwan has taken a serious look at science education and science teacher education. In general, the nation can be proud of the science achievement of its students at the K-16 levels, but many in the nation have expressed concern about student achievement; they suggest that it can be elevated beyond where it is today. They suggest that such improvement is essential if the nation is to maintain its political and economic success and its quality of life in an increasingly high technology, competitive world. Some leaders have expressed concern that the nation must not become complacent as a result of current technical success; it must continue to promote science curriculum improvements that enhance the level of students' critical thinking and problem solving. During our visits to Taiwan we have been queried consistently about how the USA has been so successful with the development of students' problem solving skills and critical thinking abilities. At the same time, we think that the Taiwanese perception, while encouraging, is not consistent with what various achievement assessments indicate about many American students. We probably have several common problems and challenges, and in some categories, such as the development of the students' technical skills, schooling in Taiwan may generally be superior to systems now in place in the USA. It is important to note that we must be very cautious about generalizing because of the major differences that are inevitable among students, teachers, schools, regions, and subcultures.

Many Taiwanese science educators are developing a strong advocacy for science instruction that is consistent with constructivist epistemology. In addition, there are sectors of support for instruction that integrates science, technology, and society as well as a small movement favoring increased instructional interactions between science and vocational teachers. Traditionally, academic and vocational curricula have been distinctly separated with little noteworthy interaction between them. The Taiwanese educational system currently tracks students into either vocationally oriented schooling or academically oriented study; in Taiwan the vocational schooling system appears to be much better developed and supported than vocational schooling in the USA.

The educational system in Taiwan continues to be dominated by an elaborate system of testing. Throughout their schooling students take rigorous examinations which determine the schools that students attend and their career options. Although Taiwan is supportive of changes in both methods of instruction and curricular emphasis, the dominance of the national examination program is a significant factor inhibiting such change unless the examining systems are modified to promote appropriate change. As in the USA, standardized testing at the state level strongly influences what teachers include in the curriculum as well as the instructional approaches used. In short, teachers in Taiwan consistently feel obligated to cover very rapidly and ritualistically much subject matter in the limited time they have for instruction. Failure to do so is thought by many parents and teachers to put the students at a disadvantage when national tests are to be taken.

Thus far, we have delineated how we have perceived the current state of science education in Taiwan as well as the emerging efforts to change. We have also described the current vision of science education reform that is visible throughout much of the world. In summary we have juxtaposed where we think Taiwan is and possible directions for future change. In the remaining sections of this paper we will attempt to elucidate what we consider to be principal assets, problems, and opportunities facing science education reform in Taiwan.

VI. Unique Assets, Challenges, and Opportunities in Taiwan

1. Rich Regional Resources

Taiwan is a country with rich *natural resources* and regional *environments*. To preserve and improve these environments people must be informed about the value, beauty, and importance of protection and nurture, etc. They need to appreciate ecosystems, to develop a sense of wonder, to be proud of them, and to have an understanding of the effects upon them of human population growth and industrialization. In addition, to promote meaningful learning students need to make connections between "school science" and their experience in daily living. Experiences in school science should enable them to connect with, appreciate, and begin to understand unique local environments and ecosystems. Rice fields, other elements of regional agriculture, local flora and fauna, and regionally relevant technologies should be visible in the science curriculum. The new 7th grade biology curriculum implemented in Taiwan in 1997 offers some examples of how authentic, regionally relevant resources can be incorporated in a life science curriculum (Editorial Committee of Junior High School Biology, 1997) This curriculum was based upon the 1997 National Curriculum Standards for Junior High School, pp. 255 - 270, published by the Taiwan Ministry of Education (1997). A physics textbook set by Tao (1997) used in schools in Hong Kong offers some examples of a textbook in the physical sciences that includes a limited number of pictures, technology applications, and historical and contemporary references that are relevant to the region and to Chinese culture. Continuing the development and implementation of a science curriculum that engages students and teachers in regionally and culturally relevant issues in science and technology is a very important opportunity.

Environmental centers, national parks, agriculture, zoos, museums, health agencies, technology centers, corporations, and professional associations have important roles to play. Some unique regional resources in the National Parks, in museums, etc., could play a continuing and powerful role in school science curricula in Taiwan. Engaging these resources may not require expenditures of large sums of money, but would necessitate bringing people and institutions together and promoting inter-institutional and inter-departmental collaboration. And the process can certainly be enhanced if the test-making community is a central part of the effort.

2. Local Technologies and Technology Tools

There are special opportunities for enhancing the science curriculum at the intersection of *science and technology*. The proper use of local resources and rich opportunities can enhance students' science learning within increasingly powerful global and regional electronic networks. Appropriate elements of these resources must find central places within the science curriculum. Contemporary ideas about science teaching suggest the importance of engaging the students in problems and experiences that are authentic to their lives and environments. Throughout Taiwan people are engaged in developing and using technologies that can supplement the science curriculum. Regional and local technologies can be both objects of study and tools when appropriate, tools that can enhance learning. Examples of the using technologies as tools is most apparent today in the opportunities provided by computer technologies, appropriate laboratory interfacing, and interactive graphics, etc.

3. Chinese Contributions to Technology and to Understanding the Natural World

Chinese astronomers, mathematicians, inventors, pharmacologists, and engineers are among those who have contributed to scientific thinking in both ancient and modern times. Their role can be made more visible to Chinese students who are learning science. To that end, it is important to examine the roles played by Chinese people in the development of mathematics, science, and technology, and to examine implications of those contributions for the science curriculum and for science learning. Taiwan offers a unique environment in which to convene international conferences on these and related concerns.

4. Energetic People Committed to Quality in Education

Taiwan's cultural strengths include an intense commitment to children and their education. The movement toward regional control of curriculum and textbook selection is a very powerful tool for empowering professional teachers, parents, and communities. Teachers and school administrators must be well prepared to handle many important challenges. What will drive school textbook selection, for example? Teacher preparation and continuing education programs need to be enhanced to make best use of the emerging opportunities.

5. Strength in Vocational Education

Taiwan has much more depth in its vocational education programs than do most countries in the world; certainly the depth is far greater than it is in North America. This depth could offer great opportunities for professional interaction between vocational teachers and science teachers. The resulting interaction could result in more appropriate and extensive applications of science in science classes (advocated but not regularly visible in classroom practice.) It could also result in more scientifically focused vocational education. The opportunity is great, but the lack of dialogue is striking. There seem to be "invisible" walls between the programs and many of the people. Although these two large communities exist side by side and have intersecting missions, the failure to have dialogue seems to have become institutionalized in the secondary schools and in the universities. However, it need not remain that way. It is also important to examine new models of collaboration that can avoid the all too frequent pecking orders of "superior" and "inferior" disciplines that are part of the traditions in other countries. These traditions have inhibited collaboration and productivity at the intersection of disciplines. Yet, today, resolving many important problems requires the collaboration of people who have transdisciplinary perspectives, knowledge, and skills.

6. Respect for Teacher and Authority

Many of the teachers we have met in Taiwan think the authority of the teacher in the classroom has been diminishing seriously in recent years. Yet, the discipline, respect for teacher, and on-task behaviors we have observed in Taiwanese classrooms would be envied by teachers in many parts of the world. There is a complex balance between the need for limiting background noise in a classroom, engaging students actively in inquiry in school science, and having students continue to show respect for the teacher and for learning that is a very important part of the Chinese culture. The questioning of models and the search for meaningful explanations about scientific ideas that should be encouraged in school science can easily be confused with disrespect for authority. There is a similar complex balance of authority when parents become more involved in the schooling of their children in a democratic society. There is another complex

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balance between the important respect for senior administrators and experienced teachers in schools and the need to empower younger teachers to try out some of the creative ideas that are present in younger generations who have had new kinds of schooling and experiences. Much care must be taken to help teachers, schools, and communities move forward toward a more scientific subculture while retaining valued elements of the Chinese and Taiwanese subcultures.

7. Engaging Experienced, Competent Teachers in Policy Making

Teachers as well as students need to be empowered as the country becomes more democratic and more highly educated. Men and women, rich and poor, need equal access to excellent educational opportunity. Competent, experienced teachers need to be appropriately engaged in school related decision-making.

8. A Science Teachers' Association

The Taiwanese do a particularly good job of providing professional development opportunities for teachers. It is not at all uncommon for teachers to be encouraged to attend national and international conferences. These conferences are attended by university faculty, administrators, and teachers alike. Although such opportunities are numerous and well intended, they sometimes may be less than optimally appropriate for classroom teachers. Conferences in Taiwan often seem to focus on important theoretical dimensions and often seem to neglect involving the teachers in more practical issues and skills development that can help them change classroom practices. As a result there is reason to be very cautious about the effectiveness of such conferences in promoting the outcomes that were intended for classroom practice. From what we have been able to observe, many science teachers in Taiwan do not have easy access to professional development that enables them to collect appropriate instructional activities, develop science teaching strategies that are relevant to their school needs, and communicate easily with colleagues about instructional strategies and activities. Taiwan does not appear to have well-developed science teacher organizations whose meetings and publications are designed to focus primarily on the practical concerns of pre-university, classroom teachers. In Taiwan, it appears that there are limited ways of enabling and encouraging the empowerment, engagement, and development of a professional community of science teachers at the secondary and possibly at the primary level. It seems that where there are professional associations of science teachers that they are discipline-based, i.e., physics, chemistry, biology, etc. While secondary school teachers may be officially "welcome" in the meetings, those meetings tend to be dominated by concerns of people in the university, not the pre-university community. Encouraging the development of an independent organization of science teachers (like the National Science Teachers Association in the USA or its equivalent in some other countries) or of science and mathematics teachers focused on the needs of primary school and secondary school teachers could be a very important move. Such an organization could independently sponsor and encourage conferences, publications, curriculum resources, and professional growth that would be especially relevant to the development of teachers at secondary and primary levels.

9. The Role of Tests in Schools and The Society

As noted earlier in this paper, the educational system in Taiwan continues to be dominated by an elaborate system of testing. Clearly, tests play a *driving* role in what teachers and students do in schools in Taiwan. Since tests are very influential, they can serve as a tool for promoting more enlightened learning and teaching when they become better integrated with the needs of the society and with carefully developed *standards* for learning outcomes.

10. Teacher Evaluation

The cultural propensity for "saving face" should not be taken too lightly in the challenging and important task of professional growth. In the current system, student teachers do not appear to be subject to serious evaluation by supervisors or mentor teachers. To do so would be perceived as very rude and inappropriate in the Taiwanese culture. Evaluation of inservice teachers is virtually non-existent. In short, once an individual becomes a certified teacher, he or she need only to meet basic responsibilities (e.g., conducting assigned classes) with no evaluation as to the quality of performance of assigned tasks. The problems with limited performance assessment and feedback extend to preservice teacher education as well. Once an individual has been admitted to a teacher education program, he or she is almost assured of completing the program and becoming a certificated teacher. The current reform movements in Taiwan properly call such practices into question. However, it remains to be seen if cultural expectations and traditions will permit the educational community to carefully evaluate a teacher's teaching performance as a primary criterion for retention and advancement in the educational system.

11. The Role of the Teacher

The approach to science instruction in Taiwan appears largely to be expository. The teacher continues to be viewed as the ultimate authority and holder of knowledge. Lecture-type instruction dominates classroom activity with the teacher delivering well over 80% of the talk in most classrooms. Periodically, teachers will ask students to contribute in order to identify their "understanding", but these instances often invoke rote responses that students can memorize. They do not normally appear to probe explanation and deeper conceptual understanding. Teachers rarely seem to use student involvement in an activity and student understanding to guide them in developing next steps in the lesson.

Class sizes are typically 40-50 students, regardless of grade level, and it is now common for the teacher to lecture using a microphone with voice amplified through small, low quality speakers. Classrooms are relatively small in size compared to classrooms in the USA, but there often is a much higher level of background noise than in American classrooms. (Also, American classrooms normally have fewer students and the teachers do not use microphones.) Many Taiwanese classrooms have windows open to loud street and school yard noises that make it difficult for students to hear their teacher without the aid of a microphone. Yet, the use of a microphone is not always necessitated by the size or by the background noise of the room. The quality of the speakers sometimes creates distortion, and it is appropriate to question whether these microphones are very helpful in achieving the goals intended for school science learning. Among other things, the presence of the microphone can easily contribute to the implicit message that the teachers' role is to talk about science while the students' role is to listen and to answer short questions.

The use of microphones by teachers conflicts with constructivist ideas that the teacher must find ways to listen to what the students are thinking (not simply reciting) and that the students must listen to and engage with the ideas of one another. On the other hand, the microphone, like other technologies, can serve useful purposes when it is used creatively and sensibly. When they are already using microphones as part of their teaching, teachers can more easily make and listen to audio tapes of their classroom "dialogue" or monologue. Such tapes could be a powerful resource in preservice and inservice teacher education. In fact, one of the authors did observe a teacher in Taiwan whose students were "teaching" her class. In that one high school classroom he observed exemplary engagement, inquiry, and dialogue among the students.

While there are noteworthy exceptions, Taiwanese science classes are not characterized by frequent laboratory work, demonstrations, and "hands-on" investigations. Students are expected to learn the necessary subject matter through lecture and reading assignments. Drill and practice oriented worksheets are common as well. At first glance, this approach to instruction works relatively well. The students do become fairly proficient with lower level knowledge of subject matter. However, it is not clear that students are learning at higher, conceptual levels of thinking.

Involving students in class discussions by asking for their opinions is seldom observed in Taiwan classrooms. Relying heavily on students' opinions and perceptions during a science lesson does not fit well in the Taiwanese cultural setting which suggests that the teacher is the ultimate authority. In short, students appear to see little use in listening to each others' opinions and perceptions about subject matter. The time seems better spent, in their eyes, with the teacher describing his or her understanding. Overall, one would characterize science instruction in most, but not all, of the Taiwan science classrooms we have visited as traditional. The teacher lectures extensively and the students dutifully take notes. Testing comprises a major motivator for students to learn since one's level of success in school as measured by the school determines students' eventual status, wealth, and respect. It is our impression that strong family support for education and the overriding perception that school achievement is essential for success later in life are strong contributors to the relative success of this instructional approach we have observed even though that approach does not seem to be consistent with contemporary constructivist views of teaching for meaningful understanding.

12. Toward Taiwanese Standards in Science, Mathematics, and Vocational Education

Taiwan needs to continue to develop regionally relevant standards for learning outcomes that are most vital for education in science and in other disciplines at each level of formal education. While Taiwan has unique resources and needs, both the standards that have been developed and the strategies that have been employed in developing them in other countries may serve as useful models for the continuing development of science education standards in Taiwan. Elements of those standards may be adapted to fit national needs in Taiwan whereas other elements will need to be designed to be especially responsive to unique resources and needs in Taiwan. The standards should have an important influence on the development of tests, the school curriculum, classroom activities, and teachers' and students' behaviors in the classroom. Needed also is the development of systems for the periodic setting and renewing of national and regional standards in science and technology for Taiwan. These systems should engage people from multiple relevant constituencies in the Taiwan society including experts in the science disciplines, in science cognition and teaching pedagogy, and from the consumers of education.

In Taiwan we have heard considerable talk about the importance of Science - Technology - Society (STS) education, environmental education, and applications of science as elements of school science. Workshops have been offered to promote some of these foci and practices, but they have tended to focus on "theory" rather than on "practice" in schools with competing demands such as academically focused tests and expectations. In the schools, there is evidence of a large gulf between that talk and the curriculum being presented to the students. The tests and the expectations of parents, teachers, and students seemed to suggest that there was little or no time in science classes for STS issues. Clarifying and identifying discrepancies between vision, goals, and practices would be an important part of the process of developing and implementing standards to guide the development of teaching practices, curriculum, and tests.

13. Opportunities for Building Bridges

A. To Chinese-Speaking Teachers in Taiwan

During our visits, it was very clear that people in leadership positions were encouraging university faculty members in science education to build important scholarly collaborations with communities in the world outside Taiwan. In this age of rapid electronic communication, international collaboration is a very important resource to continue to support; however, the support we have observed appears to have been focused largely on building connections with the "best" and "Westernized" countries such as Australia, Germany, England, the USA, etc. While that may be important for multiple reasons, it is also very important to promote the building of important bridges to the "East" including the People's Republic and to the Chinese-speaking teachers and students in the schools within Taiwan. In a science education community of limited size, the pressure to become more conversant and fluent in English, for example, could limit the time and attention given to understanding and addressing issues of special concern to Taiwanese teachers and students. It could limit the level of communication with elementary and secondary school science teachers. What, for example, are effective ways to address important competing educational priorities in Taiwanese schools when there is a science teaching staff of limited size?

B. To the People's Republic

Leaders in the People's Republic have said clearly that they wish to promote excellence in science and technology education. Where will they find leadership for regionally relevant and appropriate curriculum resources, for curriculum development, and for teacher education? It is very probable, they would prefer not to go to the "West". Taiwan has the technical skill and the infrastructure to support a very substantial educational outreach to the science education community in the People's Republic. This outreach could be very beneficial to both countries and especially to Taiwan. It could serve as one way to support the necessary university / department level fund raising that universities are said to need in coming months and years, especially for faculty in science education fields. More importantly, increased networking of skilled people in Taiwan with colleagues in the People's Republic, on the longer term, could reduce some of the political tension that is inevitably forthcoming and, in the process, could result in increased understanding and trust. That kind of extended relationship is much less probable in the "hard" sciences where the People's Republic can easily find technical support for scientific scholars in many non-Chinese parts of the world. The kind of bridge building envisioned here requires proactive construction, especially in Taiwan at the outset. It should be much more than simply allowing scholars from the People's Republic to visit when they request to do that. Scholarships could be offered to some. Invitations to selected conferences or even scholarships for sabbaticals, etc. (perhaps with subsistence support) should be offered to certain people initially. Some of this interaction could be in the best interests of individual universities and might be supported at that level.

C. To Inter-Institutional Collaboration

The growth in university infrastructure in Taiwan in recent decades has been very great. Now, voices in an increasingly democratic Taiwan are beginning to question some of that growth and the financial support necessary to sustain it. The deregulation of teacher education that commenced in 1994 is but one example. That deregulation offers important challenges and opportunities for fields like science education and for universities and public education more generally. Various universities have different strengths and are not equally staffed to support all regional service needs. For optimal leadership and response to those needs, inter-institutional collaboration should be enabled, encouraged, and developed at national policy-making as well as at local levels... Similarly, greater inter-departmental collaboration is needed within universities.

14. Priorities in University Science Education Programs and in the Science Education Program of the National Science Council (NSC)

Universities have important missions in teaching, research, and service, and increasingly faculty members are expected to have high levels of scholarly productivity. The community needs to ask: what are the principal purposes of the scholarship that is desired? Decisions about how to promote scholarly productivity should be based upon the kinds of scholarship that are desired. While engagement and dialogue with international scholarly communities may be an important element of scholarship today, in a field like science education, good scholarship should also inform national and regional *policy* and *practices*. The development of appropriate research skills demands significant time commitments. In some of the universities we visited, instructors were investing much time in teaching many classes with very small enrollments, *i.e.*, 2 - 5 students; teaching similar classes of 10 - 30 students would not have involved significantly more preparation time for faculty members. The competing demands for time were inhibiting the productivity of some members of the faculty who seemed to feel that they were unable to change the expectations of the institution in which they were working. How can teaching loads, assignments, and scholarly expectations be readjusted to enable greater productivity consistent with important contemporary priorities and goals?

VII. Toward Excellence in Science Teacher Education

The Normal University approach to teacher education that Taiwan has had in past years can be argued to be more consistent with current reforms than the popular Master of Arts in Teaching (MAT) approach used in the USA. The MAT approach typically "front loads" subject matter knowledge as a requirement for admission and focuses primarily on the application of pedagogy to subject matter knowledge already possessed. The Normal University approach integrates the development of subject matter knowledge and pedagogy.

Current international reforms in science education have recognized the significance and power of field-based experiences. This idea is not new, but in the past teacher education programs have swung back and forth between maximized or minimized field experiences. The current reforms recognize that an important balance must be struck between the theoretical and applied aspects of professional development and teacher education. Field experiences are enhanced by theoretical background and teachers with strong field experiences benefit more from the more theoretical aspects of science teacher education.

Perhaps the most important position taken by current reform movements in the area of teacher education is that teaching can not be reduced to the performance of a prescribed set of behaviors. Rather the teacher is a thinking professional who is required to make numerous "on the spot" decisions in response to students' behaviors, knowledge, and level of understanding. There is simply no one best way to teach all students in all situations.

The current reforms have delineated a vision of what science teaching should be like across grade levels. This vision has had clear implications for how our future science teachers need to be prepared and how current classroom teachers can attempt to change. Naturally, the success of teacher education reform efforts is unavoidably dependent upon the quality of approaches used in the evaluation of teachers. How do we best assess teachers' understanding of subject matter, students, schools as communities, assessment practices, general pedagogy, etc.? To be consistent with the model of a teacher as a professional the reform efforts have attempted to move the evaluation of teachers away from detached paper and pencil tests and biased classroom observations. Rather, the reforms have advocated that teachers should be evaluated and receive feedback in the same way the reforms are advocating that teachers should evaluate their own students. To that end, in an attempt to develop an evaluation system that authentically evaluates what a teacher knows and can do, a portfolio system has been a very popular recommendation. The teacher is expected to purposefully collect materials that can serve to document his/her ability to foster learning and successfully interact with students. These materials (sometimes called artifacts) may include such items as lesson plans, student work, videotapes, etc. The teacher is expected to put together a set of materials that supports the teacher as an effective professional. Importantly, portfolios must be viewed as placing teachers along a continuum of lifetime professional growth. The teacher is never a finished product, never a perfect teacher. Consequently, portfolios are expected to contain statements of the teacher's intentions and goals and subsequent data to indicate the teacher's progress toward achieving the stated goals.

Teacher education is one aspect of the Taiwanese educational system that is currently under serious scrutiny. Previously only three Normal Universities" were charged with the preparation of secondary school teachers in Taiwan and nine Teachers Colleges" prepared elementary school teachers. Recently the Ministry of Education approved a policy that allows any institution of higher education to offer programs in teacher education. As a consequence of this significant change in the education of teachers, there is serious concern about the quality of teacher education programs. Taiwan has an opportunity to use these concerns as bases for setting new standards for teacher certification. In addressing these standards, it will be important to examine the expectations in both *disciplinary* knowledge and *pedagogical* knowledge since the teacher must posses skills in both for optimum effectiveness. Is one of these forms of knowledge and practice being emphasized in Taiwanese teacher education at the expense of the other?

From our perspective, a serious consideration of the validity and effectiveness of each aspect of science teacher preparation is needed in Taiwan and everywhere else. Two significant changes in science teacher education have developed that represent a clear consequence of current concerns about the quality of teacher preparation. Beginning teachers are now required to complete a trial period or *apprenticeship* during their first year of teaching. This apprenticeship is in addition to the student teaching internship during the teacher preparation program. The teaching internship completed during one's teacher education program has typically been about one month in duration with little actual teaching experience and a level of supervision that is very inadequate, in general. Taiwanese officials have recognized the inadequacy of the traditional system of supervision and are now requiring beginning teachers to demonstrate their skills and knowledge during an initial year of employment as an apprentice teacher. While performance evaluation rules have been specified, it remains to be seen how rigorous and consistent the evaluation of teachers will be during this "apprenticeship" year.

The second consequence of these concerns about the preparation of science teachers has been the emergence of a variety of efforts to reform the current system of teacher evaluation. In particular, several universities in Taiwan are involved in multi-year studies to develop "standardized" instruments for the evaluation of beginning teachers. This attempt marks the beginning of a significant change in how Taiwan has traditionally handled the evaluation of teachers. Within the Taiwanese culture, critical comments about the job performance of another teacher have not been encouraged. *Saving face* is very important in Asian cultures, at a level that is much more intense than in western cultures. Indeed, there is even difficulty in using evaluative terms on the evaluation instruments. Some educators support authentic types of assessment such as portfolios, but the concern with portfolios is much the same as in the USA and elsewhere. That is, portfolios are very labor intensive for both the evaluator and the person being evaluated. There is also a strong predisposition for more quantitative approaches to evaluation, resulting in a quest for the perfect observation instrument. Diverse efforts are now under way with no clear resolution of the systems that will emerge in the future. It is probable that different kinds of systems can be made to work effectively, and as development occurs, some oscillation between strategies and between emphases will be unavoidable. The important matter is that policy making should be informed by objective data and research that reflects what we know about how students and teachers learn and develop. Fortunately, efforts to develop and examine systems of teacher evaluation more consistent with contemporary constructivist, socio-cultural, and contextual concerns, have been supported by organizations like the National Research Council. Policy making should not be based on what is fashionable in the West or in the East! Good educational research should be employed regularly by policy makers to help learners and teachers to find "the shoulders of the giants" in science and in science teaching practice.*

*The last sentence is a paraphrase of Isaac Newton with much artistic license.

VIII. Engaging Cultural Traditions and Regional Resources Productively

In this world of rapidly increasing high technology, developing high quality science education programs for all the people is a continuing and important challenge. Clearly, these are times of great change. The new technologies, values, and ideas are powerful double-edged swords that can enhance or inhibit the further development of a great and ancient culture, the empowerment of people, and the quality of life. Similarly, alternative solutions for science education and schooling can be double-edged swords in the lives of the people, the nation, and the culture. In every region there are rich local and regional resources that ought to be very visible in schooling. In every culture there are rich and valued traditions that are worth understanding, preserving, and enhancing. Taiwan is no exception. In this age of instant global communication and technology, each of our countries does not need to Reinvent the wheel, and we do need to understand and to use appropriately ideas and tools from beyond local shores. There are, as well, ideas and technologies that we should decide *not* to import and use. In Taiwan it will be important continually to examine ideas from within and without in order to adapt what is appropriate to important, unique needs and rich cultural heritage. Well conducted research should inform the examination of such ideas and the development of education policy and school practices. We are looking forward to observing the models that will be developed in Taiwan.

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台灣科學教育改革的情境、機會和值得關注的重點

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摘 要

九十年代科學教育改革之必要已廣泛地被討論，並且在國際間一致推動科學教育改革浪潮下，台灣在改善科學教育本質方面更是不遺餘力。這篇報告是兩位 國際訪問學者在深入了解台灣所做的努力之後而做的評論。文中以全球性的變 動和台灣本身制度上的改變爲背景，描繪出台灣科學教育的改革。這篇報告也進一步說明了台灣面對科學教育改革所具有的獨特資源、問題和契機。對於納 入台灣豐富的區域性資源、本地科技和科技發展設備、中國人在科技及對自然界認知上的貢獻、職業教育的優勢和文化傳統等特受重視事項的必要性，在文中亦簡要予以檢視。另外，考試制度在學校及社會的角色扮演、科學師資教育、 教師評鑑及如何讓教師參與學校政策的制定等相關課題也在本文提及。文中最後論及研擬科學教育標準並納入特別是關乎台灣人民的需要、現況及文化的地域性資源和範例的必要性。

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以英文刊登高水準科學教育學術論文，多年來本會以不斷提高其內容水準爲職志。本刊原爲半年刊，已於八十六年元月起改爲一年三期，每年一月、五月、九月出版。本刊寄送國內253個單位，國外76國，約1290個大學圖書館、學術研究機構及國際著名之資訊檢索服務機構，現並已爲ERIC資料庫所收錄。

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