Instructional Effect of Cooperative Learning in Problem-Solving Strategy*

Kyungmoon Jeon**

Gwangju National University of Education

Taehee Noh***

Seoul National University

Abstract

In this study, we investigated the effect of the instructional approach that asked students to check their planning in a cooperative learning environment after presenting a four-stage problem-solving strategy. Three high school chemistry classes (N = 101) were randomly assigned to one of three groups; IND group (using problem-solving strategy individually), COOP group (using problem-solving strategy in cooperative learning group), and comparison group (traditional instruction). After instruction, students' problem-solving performance and chemistry conception were compared. The results showed a significant interaction between the treatment and the previous achievement level in students' problem-solving performance. Analyses of

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** Department of Science Education, Gwangju National University of Education, Gwangju, Korea, 500-703; E-mail: kmjeon@gnue.ac.kr

*** Department of Chemistry Education, Seoul National University, Seoul, Korea, 151-741; E-mail: nohth@snu.ac.kr

simple effects indicated that the low-level students in the COOP group performed better on recalling related laws and organized progression than those in the other groups. This may be due to the fact that they were taught to recall the related concepts or principles in the planning stage, and had small group interaction about the appropriateness of their planning. In the case of the conception test, the high-level students in both the IND and COOP groups understood chemistry concepts better, while the low-level students in only the COOP group acquired more chemistry concepts. However, most students perceived that cooperative learning helped them acquire problem-solving strategy, and they also preferred the instructional types that included cooperative learning strategy. Educational implications are discussed.

Key words: chemistry problem solving, problem-solving strategy, planning, cooperative learning.

I. Introduction

Problem solving is bridging a gap between a problem state and the solution state, and is the result of an application of knowledge and procedures to a problem situation (Ashmore, Fraser, & Casey, 1979). Fostering the ability to solve problems is a major objective in science courses (Kuo, Heller, Heller, Henderson, & Yerushalmi, 2000; Lochhead, 2000; Lyle & Robinson, 2001; Pestel, 1993), and its achievement is usually measured by the number of problems that a student has correctly solved on a test

(Bascones, 1985). However, many students, even after instruction, still have difficulty in solving problems and do not know how to get started. They continue to use novice problem-solving skills rather than more advanced problem-solving skills (Asieba & Egbugara, 1993; Maloney, 1994; Mettes, Pilot, Rookssink, & Kramers-Pals, 1980). Problem solving has also been a stumbling block for many students enrolled in chemistry courses (Gabel & Bunce, 1994).

Many researchers have focused their attention on developing systematic problem-solving strategies (Abel, 2003). Over 60 different problem-solving strategies have been described in the literature, but many seem to describe similar procedures with slightly different terms (Woods, 1989). Polya's strategy in the context of mathematics, probably the most well-known one, has the following four stages: 1) understanding the problem, 2) devising a plan, 3) carrying out the plan, and 4) looking back over the process (Polya, 1945). Another four-stage strategy suggested by Mettes and his colleagues (Mettes, Pilot, Rookssink, & Kramers-Pals, 1980) consists of the following stages: 1) analysis of the problem, 2) transformation of the problem into a standard problem, 3) execution of routine operations of the standard problem, and 4) checking the answer and interpretation of the results. Frank and Herron (1985) also illustrated a three-phase strategy in chemical education. It was based on Polya's model, but the first two stages were combined into one called 'planning the solution'.

However, not all of the instructions where students learn these heuristics have produced evidence of enhanced student problem-solving ability (Pestel, 1993). At first, some suggest that strategies with too many stages have little effect, partly because it can be too time-consuming and students tend not

to use it. For example, Bunce and Heikkien (1986) found in their six-stage strategy (statement, sketch, recall, solution diagram, mathematical solution, and review) that students who used the strategy tended to be less successful in solving chemistry problems.

Many studies indicated that planning is one of the most difficult problem-solving skills for students to learn (Dalby, Tourniaire, & Linn, 1986). Huffman (1997) investigated the effect of a problem-solving strategy (focus the problem, describe the physics, plan the solution, execute the plan, and evaluate the solution) on five different characteristics of expert-like problem solving, which were quality of physics representation, completeness of physics representation, match of equations, organized progression, and mathematical execution. It was found that there was no significant difference between the problem-solving strategy and textbook problem-solving strategy groups on organizing a solution, although the treatment group was directly taught to write a plan for solving problem and the comparison group using textbook was not. Further studies are needed to develop a problem-solving strategy which emphasizes the importance of the planning stage and an instructional approach leading to effective learning of planning skills (Montague, 1992).

An alternative important factor in solving problems is the content knowledge needed for arriving at a solution (Ben-Zvi & Gai, 1994; Gabel, Samuel, & Hunn, 1987). Noh and Jeon (1997) investigated the instructional effect of a four-stage problem-solving approach emphasizing the concept of the molecular level of chemistry. It was hypothesized that conceptual understandings, and thus more accurate problem representations at the molecular level, may be crucial to successfully solve quantitative chemistry problems (Noh & Scharmann, 1997; Williamson & Abraham, 1995). However,

there was no significant difference in the performance of solving problems, although the conceptual understanding of chemistry of the treatment group was improved.

Mastery of problem-solving activities goes far beyond the theoretical knowledge of heuristics (knowing how) or concepts (knowing what), and requires the integration of various skills (Taconis, Ferguson-Hessler, & Broekkamp, 2001). One key component of fostering problem-solving ability is, then, providing feedback and support to enable students to monitor their progress towards a solution to a problem, as well as introducing problem-solving strategies or emphasizing the basic concepts (Asieba & Egbugara, 1993; Collins, Brown, & Newman, 1989; Keith, 1993). For example, cooperative learning can help students observe and understand their own thought processes and those of their fellow students (Duren & Cherrington, 1992; Hassard, 2000; Huffman, 1997; Tingle & Good, 1990). Cooperative learning is not a new idea and has been used in many science courses of secondary schools and universities. Tingle and Good (1990) investigated the effect that cooperative groups formed heterogeneously on the basis of proportional reasoning ability have on problem solving in regular and honors high school chemistry with a problem-solving strategy consisting of statement, redescription, prediction, mathematical solution, and checking. They found no statistically significant difference in posttest scores between the students of varying proportional reasoning abilities who solved problems individually and cooperatively. Further research is needed to understand cooperative learning better as a method to monitor and check students' problem-solving processes.

Given the need for more instructional studies of problem-solving strategies and the expectation that cooperative learning environment may help students acquire the strategy,

this study was designed to investigate the effect of the instructional approach that asked students to check the appropriateness of their planning in a cooperative learning environment after presenting molecular-level pictures and a four-stage problem-solving strategy. The interaction effect between the instructional method and the level of prior achievement was also investigated.

II. Method

A. Subjects

The sample for this study was taken from a girls' academic high school in Seoul. Most students at this school were from a lower middle class socio-economic level. Three declared science major class groups, with a total of 101 11th-graders, were selected, and randomly assigned to either a group that used a problem-solving strategy individually (IND group), a group that used a problem-solving strategy in a cooperative learning environment (COOP group), or a group that used traditional instruction (comparison group). Students in each group were also divided into high- (50%) and low-levels (50%) by their previous chemistry achievement.

B. Procedures

The comparison, IND, and COOP groups were taught by the same teacher, who had 18 years of teaching experience. The teacher was given sample solutions of problems using a four-stage problem-solving strategy and guidelines on cooperative learning as defined by Johnson and Johnson (1989): positive interdependence, face-to-face interaction,

individual accountability, social skills, and group processing. He practiced the instructional approaches at least once before teaching the groups. Before instruction, chemistry and mathematics course grades were analyzed to establish the quasi-equivalence of the three groups. The IND and COOP groups were first given two class hours of orientation on problem solving (Asieba & Egbugara, 1993) using the four-stage strategy individually and cooperatively respectively. The content covered during five class hours of this study was about 'gases'. The problem-solving strategy was applied to algorithmic problems related to Boyle-Charles' law, ideal gas equation, Graham's law of diffusion, and Dalton's law of partial pressure. One of the researchers made classroom observations and discussed with the teacher about the overall instructional progress of the three groups. After the instruction, a problem-solving test, a conception test, and two questionnaires of students' perception on the new treatment were administered.

C. Instructional Approaches

In the first part of each class, the teacher introduced new chemistry concepts, laws, and principles with an emphasis on molecular representation through a pictorial presentation in the IND and COOP groups. The researchers adapted the representation from other sources, when a proper picture was not found in the textbook (Table 1). The students were taught how to solve problems using the four-stage problem-solving strategy. The strategy consists of the following steps: a) understanding, b) planning, c) solving, and d) reviewing. The steps of this strategy were influenced by several studies in chemistry or mathematics (Bunce & Heikkinen, 1986; Frank & Herron, 1985; Keith, 1993; Mettes,

Pilot, Roossink, & Kramers-Pals, 1981; Polya, 1945), and were also used in our previous studies (Jeon, Huffman, & Noh, in press; Noh & Jeon, 1997). The teacher emphasized the importance of the planning stage (Montague, 1992) and checked the appropriateness of planning at the end of each problem solving, because planning is one of the most difficult problem-solving skills for novices to learn (Dalby, Tourniaire, & Linn, 1986). An example of how to solve a problem using the strategy is shown in Figure 1.

During the last part of each class, the students solved problems under the guidance of the teacher. The students in the IND group used the four-stage problem-solving strategy individually with very little interaction, while those in the COOP group used the four-stage strategy in four-member heterogeneous groups formed on the basis of their previous chemistry achievement levels. Students were assigned to the roles of manager, record keeper, questioner, and material keeper, and switched their roles from class to class. Role cards and worksheets were used. Each group member discussed how well they were achieving their goals and maintaining effective working relationships at the end of cooperative problem solving (Heller, Keith, & Anderson, 1992; Johnson & Johnson, 1989). The students in the IND and COOP groups were asked to check if the planning was appropriate after solving each problem. The comparison group was instructed with a traditional expository teaching method and textbook approaches for problem solving. To control the time-consuming nature of cooperative learning, the students in the comparison group solved more problems than those in the other groups.

Table 1. Comparison of instructional approaches

	Comparison	IND	COOP
Lecture (20 min)	traditional	emphasizing molecular level	emphasizing molecular level
Teacher's problem solving (10 min)	traditional	four-stage strategy emphasizing planning stage	four-stage strategy emphasizing planning stage
Students' problem solving (20 min)	traditional	four-stage strategy emphasizing planning stage	four-stage strategy emphasizing planning stage and cooperative learning

(Effusion of gas) Hydrogen and oxygen gases effuse from a very tiny hole of the balloons that contain each gases. If these two gases are placed under the same conditions, calculate the mole ratio of effusion. Molar masses of hydrogen and oxygen are 2 and 32, respectively.

Understanding

Grasp the given and unknown variables

molar mass of hydrogen = 2

molar mass of oxygen = 32

the mole ratio of effusion?

Planning

Recall the related concepts or principles

Translate the problem description into mathematical representation

$$\frac{v_{H_2}}{v_{O_2}} = \sqrt{\frac{M_{O_2}}{M_{H_2}}}$$

the mole ratio of effusion = the relative rates of effusion

Solving

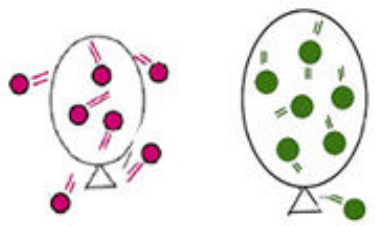
Execute the plan

$$\frac{v_{H_2}}{v_{O_2}} = \sqrt{\frac{M_{O_2}}{M_{H_2}}} = \sqrt{\frac{32}{2}} = 4$$

Reviewing

Check the calculation

Evaluate the meaning of the answer



Hydrogen gases effuse four times faster than oxygen gases under the same condition.

Checking the appropriateness of your planning

What were the related concepts or principles?

How did you translate the problem description into mathematical representation?

Was your planning appropriate to solve this problem?

Figure 1. Example solution using the four-stage problem-solving strategy emphasizing the planning stage

D. Instruments

1. Problem-Solving Test

An essay-type problem developed in our previous study (Jeon, Huffman, & Noh, in press) was used. It was designed to assess how well students use the problem-solving

strategy. The problem is taken from a real-world context, does not explicitly identify unknown, and also provides more information than needed to solve the problem (Heller & Hollabaugh, 1992; Huffman, 1997). This test is shown in Figure 2.

> A store sells 30-L closed tank of compressed gases such as oxygen, hydrogen, LPG, and butane. The tank has a gauge indicating the inside pressure, and both the inside and outside temperatures are same. One day last summer with the temperature of 27 ℃ the store keeper sold a tank of hydrogen with 16 atm at ₩ 00,000 and a tank of butane with 16 atm at ₩ 25,000. On a cold winter day with a temperature of -3 ℃ a tank of hydrogen with 9 atm has been sold at ₩ 25,000. The storekeeper claimed that the price of hydrogen this winter is lower than that in last summer. Is this claim reasonable?

Figure 2. An essay-type problem-solving test

The quality of the solutions was judged using the characteristics of expert-like problem solving that included grasping the given variables, conceptual knowledge, recalling the related laws, organized progression, and mathematical execution (Table 2). To make comparisons more easily among five different characteristics that were scored, each of the five scores were equally weighted by translating them to a three-point scale for a total maximum score of 15 points. To assess the reliability of grading, two coders practiced using the scoring rubric that was identified in analyzing the results of pilot tests. Any discrepancies of grading were discussed to reach consensus in scoring. After intercoder agreement was established to be .93, grading was carried out by one of the researchers.

2. Conception Test

A conception test consisting of 2 items regarding 'temperature and pressure of gases' and 'number of gas molecules and pressure' was developed based on our previous study (Noh, Jeon, & Kim, 1996). Drawing pictures at the molecular level and written explanation were used for modes of responses. Students' conceptions were classified into 3 categories: sound understanding (2 points); partial understanding with some misconceptions (1 point); misconception or no understanding (0 point). The intercoder reliability of the conception scoring was .96.

3. Questionnaires of Students' Perception on Treatment

To investigate students' perceptions on the new teaching method, two questionnaires were administered to the COOP group (n = 34). One was concerning the effect of cooperative learning on acquiring strategy ("Did cooperative learning help you to understand or acquire four-stage problem-solving strategy?"). The other asked students to choose their preferred instructional type ("Which instructional type do you prefer for chemistry class?").

E. Data Analysis

First, chemistry and mathematics course grades were analyzed to establish the quasi-equivalence of the three groups, although students are usually assigned to one of the several equivalent class groups on the basis of their overall academic achievement at the previous grade. The result of the one-way ANOVA indicated that there were no significant

Table 2. Problem-solving scoring rubric

1. Grasping the given variables
0- Nothing written
1- Most variables are missing
2- Grasping the given is almost complete
3- Grasping the given is complete
2. Conceptual knowledge
0- Nothing written or no understanding
1- Partial understanding of chemistry concept (with some misconceptions)
2- Sound understanding of chemistry concept
3. Recalling the related laws
0- Nothing written
1- Law is inappropriate
2- Law is appropriate
4. Organized progression
0- Nothing written
1- Unorganized progression (haphazard manipulation)
2- Incomplete organized progression
3- Complete organized progression
5. Mathematical execution
0- Nothing written
1- Inappropriate math is used or execution is stopped halfway
2- Aside from minor mistakes, execution is correct and complete

differences among the groups (chemistry, MS = 342.11, F = 1.72, p = .185; mathematics, MS = 374.61, F = 1.29, p = .280). To determine whether students in the IND and/or COOP groups showed higher problem-solving performance or conceptual understanding than students in the comparison group, scores on the essay-type problem-solving test and conception test were compared using the 3× two-way ANOVA. When the significant interaction between treatment and previous achievement level was found, the Kruskal-Wallis test was conducted for simple test. In the cases of significant

χ^2, post-hoc comparisons between groups were conducted using the Dunn method (Siegel & Castellan, 1988).

III. Results

A. Problem-Solving Test

The results of the essay-type problem-solving test are summarized in Table 3. In the case of the low-level students, the mean score of the COOP group (10.15) was higher than those of the comparison and IND groups (6.32 and 6.06), while the mean scores of the high-level students in the three groups were similar. As shown in Table 4, the *F*-value for the interaction between the treatment and the previous achievement level was statistically significant (F = 3.17, p < .05), although there was no main effect of treatment. The simple test (χ^2 = 8.32, p < .05, Table 5) followed by post-hoc comparison using the Dunn method (p < .01) indicated that the low-level students in the COOP group performed better than those in the other groups.

Table 3. Means[1] and standard deviations of problem-solving test scores by group and level

	Comparison (n = 32)	IND (n = 35)	COOP (n = 34)
High (n = 51)	11.11 (3.39)	11.26 (3.45)	10.68 (5.20)
Low (n = 50)	6.32 (3.81)	6.06 (4.09)	10.15 (4.94)
Total	9.02 (4.27)	8.89 (4.54)	10.37 (4.98)

[1] Full score = 15.

Table 4. Two-way ANOVA of problem-solving test scores by group and level

Source of variation	*SS*	*Df*	*MS*	*F*
Treatment	65.59	2	32.80	1.87
Treatment × evel	110.92	2	55.46	3.17*
Residual	1664.56	95	17.52	
Total	2128.19	100	21.28	

*p<.05.

Table 5. Kruskal-Wallis test results of each level on problem-solving test scores

Previous achievement level	Mean rank			χ^2
	Comparison	IND	COOP	
High	25.00	26.24	26.96	.15
Low	21.11	20.28	32.75	8.32*

*p<.05.

The success rate of the low-level students on the essay-type problem-solving test was also higher in the COOP group than in the other groups. Eight (40%) of the 20 low-level students in the COOP group were successful (Table 6), whereas none of the 14 in the comparison group and only two of the 16 low-level students in the IND group were successful.

To compare specific characteristics of the problem-solving solutions, the low-level students' subscores on the essay-type problem-solving test were also analyzed (Table 7). The Kruskal-Wallis test and post-hoc comparisons showed that the students in the COOP group performed better than those in either the IND or comparison groups on recalling the

related laws (χ^2 = 16.57, p < .001) and organized progression (χ^2 = 6.00, p < .05).

Table 6. Frequency of students successfully solving the essay problem

	Comparison	IND	COOP
High	7 (n = 18)	8 (n = 19)	7 (n = 14)
Low	0 (n = 14)	2 (n = 16)	8 (n = 20)
Total	7	10	15

Table 7. Means[1] and standard deviations of the low-level students' problem-solving test

	Comparison (n = 14)	IND (n = 16)	COOP (n = 20)
Grasping the given variables	2.00 (.96)	2.19 (1.05)	2.25 (.91)
Conceptual knowledge	.43 (.92)	.47 (.90)	1.28 (1.48)
Recalling related laws	.75 (.98)	.94 (1.33)	2.48 (1.12)**
Organized progression	1.43 (1.16)	.88 (1.15)	1.90 (1.29)*
Mathematical execution	1.71 (1.30)	1.59 (1.02)	2.25 (1.14)

[1] Full score of each subcategory = 3.
*p<.05, **p<.001.

B. Conception Test

Descriptive statistics for the conception test scores are shown in Table 8. The high-level students in the IND (3.16) and COOP groups (3.14) acquired higher scores than those in the comparison group (1.83), while the mean score of the low-level students in the COOP group (3.60) was higher than those of the other groups. Two-way ANOVA results showed that there were both main effect of the treatment and interaction effect between the treatment and the previous

achievement level (Table 9). The simple test (Table 10) followed by post-hoc comparison indicated that the high-level students in both the IND and COOP groups understood chemistry concepts better (KW: χ^2 = 9.40, p < .01; Dunn: p < .001), while the low-level students in only the COOP group acquired new chemistry concepts (KW: χ^2 = 12.21, p < .01; Dunn: p < .001).

Table 8. Means[1] and standard deviations of conception test scores

	Comparison (n = 32)	IND (n = 35)	COOP (n = 34)
High (n = 51)	1.83 (1.43)	3.16 (1.43)	3.14 (1.61)
Low (n = 50)	2.29 (1.20)	2.00 (1.75)	3.60 (.94)
Total	2.03 (1.33)	2.63 (1.66)	3.41 (1.26)

[1]Full score = 4.

Table 9. Two-way ANOVA of conception test scores by group and level

Source of variation	*SS*	*Df*	*MS*	*F*
Treatment	28.23	2	14.11	7.19**
Treatment × evel	14.68	2	7.34	3.74*
Residual	186.40	95	1.96	
Total	233.09	100	2.33	

*p<.05, **p<.01.

Table 10. Kruskal-Wallis test results on conception test scores

Previous achievement level	Mean rank			χ^2
	Comparison	IND	COOP	
High	17.67	30.68	30.36	9.40*
Low	19.93	19.72	34.03	12.21*

*p<.01

C. Perception on Treatment

Over 90% of the students in the COOP group (n = 34) showed positive perceptions on the effect of cooperative learning strategy in acquiring the problem-solving strategy (Table 11), while only three high-level students responded as 'no help'. Many students perceived that cooperative learning strategy helped them acquire planning strategy. Table 12 summarizes the students' responses to their preferred instructional type in the COOP group. Over 80% of the students preferred cooperative learning strategy regardless of the use of the problem-solving strategy.

Table 11. Students' response frequency to the effect of cooperative learning strategy in acquiring problem-solving strategy (%)

	Understanding	Planning	Solving	Reviewing	No help
High	4	8	3	2	3
Low	10	15	5	4	0
COOP total (n = 34)	14 (29.6)	23 (42.6)	8 (14.8)	6 (11.1)	3 (5.6)

Table 12. Students' response frequency to preferred instructional type (%)

	Traditional	Using a problem-solving strategy individually	Cooperative learning strategy	Using a problem-solving strategy cooperatively
High	1	1	7	5
Low	1	3	7	9
COOP total (n = 34)	2 (5.9)	4 (11.8)	14 (41.2)	14 (41.2)

IV. Discussion and Conclusion

The results of this investigation indicated that the instructional approach combining the teaching of a problem-solving strategy with practice implementing cooperative learning strategy was effective in improving the problem-solving performance of the low-level students (COOP group), while the prescriptive problem-solving strategy itself did not result in greater improvement for the students in the IND group.

The low-level students in the COOP group showed greater success on the essay-type problem-solving test (40%) than those in the comparison and IND groups (0% and 12.5% respectively; Table 6). They demonstrated higher performance especially on recalling the related laws and organized progression (Table 7), although planning is considered to be one of the most difficult problem-solving skills for novices to learn (Huffman, 1997; Noh & Jeon, 1997). The higher performance may be due to the fact that the low-level students in the COOP group were taught to recall the related concepts or principles in the planning stage, and had small group interaction about the appropriateness of their planning (Figure 1). These students also exhibited better understanding in the conception test. In the processes of justifying statements, clarifying ideas, and elaborating on explanations, the students appeared to be deepening their conceptual understanding (Heller & Hollabaugh, 1992).

It is therefore recommended that chemistry instructors increase the use of problem-solving strategies rather than textbook strategies, while considering a decrease in the quantity of assigned problems with greater emphasis on the problem-solving process. They should also monitor the

cooperative group work and give feedback only as needed instead of answering students' questions immediately (Tingle & Good, 1990).

In the case of the high-level students, the scores of the conception test of both the IND and COOP groups were higher than that of the comparison group. The IND group was given the molecular level representation and detailed instruction how to recall the related concept and how to review the meaning of answer. The additional instruction that the IND group received helped the high-level students understand chemistry concepts better (Gabel, Briner, & Haines, 1992; Russell & Kozma, 1997; Smith & Metz, 1996) regardless of peer interaction in a cooperative learning environment.

Although cooperative learning had a positive effect upon only low-level students' conceptual understanding or problem-solving performance, there was some evidence that the students of all achievement-levels may like cooperative learning. Most students in the COOP group perceived that cooperative learning helped them develop problem-solving strategy (Table 11), and they preferred the instructional types that included cooperative learning strategy (Table 12).

A suggestion for further research concerns the efforts to maximize the effect of cooperative learning for all achievement-levels of students. The effects of various groupings in cooperative learning, for example, heterogeneous vs. homogeneous achievement grouping (Webb, 1982) or grouping by other cognitive/affective variables, need to be studied. Well-chosen study materials, guidelines, or feedback should be considered for more profitable learning conditions in small group activities (Taconis, Ferguson-Hessler, & Broekkamp, 2001). Another suggestion is regarding social problem-solving behaviors in cooperative learning to find which types of

verbal behaviors lead to higher problem-solving performance (Nattiv, 1994; Webb & Farivar, 1994).

More studies are also needed regarding various instructional approaches leading to effective learning of planning skills (Dalby, Tourniaire, & Linn, 1986; Montague, 1992). Isolating the most effective elements of planning, developing new strategies emphasizing the planning stage, or guiding students to perceive the importance of planning in problem solving is needed. ICT (Information, Communication, and Technology), for example, could be used. Guidelines and immediate feedback could be implemented as well to create an adequate learning environment for developing problem-solving strategies (Taconis, Ferguson-Hessler, & Broekkamp, 2001). We should also try to develop a more valid and more reliable instrument for students' problem-solving performance or planning skill (Huffman, 1997).

Although this experimental study was conducted in a natural setting and the researchers attempted to ensure the intended treatment, the scale of the study was small. The final suggestion is therefore more replication studies involving more teachers and/or more students including boys to get greater generalizability of the findings.

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