CHAPTER THREE

Gender Difference in Collaborative Learning and Learning with Hints

Abstract:
This empirical study explores the gender difference in two heuristic methods: collaborative learning and individual learning with hints. We constructed four experimental conditions: collaborative learning with hints, collaborative learning without hints, individual learning with hints, and individual learning without hints. Ninety-nine students from a secondary school in Shanghai participated in the study which had a pre- and posttest design. Besides the individual learning without hints condition, we found a significant gender difference in the collaborative learning without hints condition within which male students outscored female students. But this was not the case in the other two conditions: collaboration with hints and individual learning with hints. Based on these results, some suggestions for future research and practical implementation are offered.

3.1 Introduction
Problem solving skills encompass a vast range of activities including higher order thinking skills such as visualization, association, abstraction, comprehension, manipulation, reasoning, analysis, synthesis, generalization – each needing to be ‘managed’ and coordinated’ (Garofalo & Lester, 1985; Polya, 1957). Solving problems depends not only on the proficiency in recalling an equation or doing some symbol manipulation, but on systematic analyses of problem information, syntheses of various solving methods and critical reflection on the answer.

2. This chapter is based on Ding, N. & Harskamp, E.G. (2009) Gender Difference in Collaborative Learning and Learning with Hints, submitted to Journal of Experimental Education
Physics education needs to be geared toward helping students develop a more flexible understanding of concepts and principles in order to solve novel problems (Henderson & Dancy, 2004). However, it is frequently reported that students have trouble in hypotheses setting, knowledge representation, planning and monitoring the process (de Jong & van Joolingen, 1998), and cannot relate their algebraic manipulation to the given problem situation (McDermott & van Zee, 1985). They may have the necessary prior knowledge but still get lost in problem solving (Sfard, Neisser, Streefland, Cobb & Mason 1998). King (1990) pointed out that students do not spontaneously generate highly elaborate explanations or questions on their own. Many students see problem solving as an independent process, largely unaware of the concepts and principles being taught (Heller & Hollabaugh, 1992). They tend to use taught procedures uncritically, seeking for a specific formula suiting the given problem situation and going on mathematical “wild goose chases” (Schoenfeld, 1992; Sherin, 2001).

With an attempt to improve students’ problem-solving performance in physics, researchers have tried various instructional strategies. For example, Heller and Reif (1984) suggested to use explicitly taught strategies to structure students’ problem solving process. Heller, Keith and Anderson (1992) have also recommended collaborative problem solving as a way to enhance students’ performance. Both methods hinge on the constructivism stressing that knowledge is constructed through the experience that the learner negotiates with the object and develops the metacognitive abilities to direct own learning. In the past twenty years, both collaborative learning and individual learning structured by strategies are widely adopted in classroom instruction. However, research of Heller and Hollabaugh (1992) indicated that female and male students may benefit differently from collaborative problem-solving. There raises a question in practice, which method is better in closing the gender gap.

This article reports on a study that investigates the effect of collaborative learning and instructional strategies on students’ learning achievement, and explores whether a new heuristic method, structured collaborative learning, helps alleviate the gender gap in physics problem-solving. In the sections that follow, we will elaborate on the theoretical and empirical support of collaborative learning and instructional strategies, respectively. Subsequently, we will give an account of the methodology of the experiment. Following this, the results and several case studies will be given. Finally, some suggestions for future research and practical implementation will be offered.

3.2 Collaborative Learning

Collaborative learning refers to a heuristic methodology that students engage in a common task, working jointly to co-construct the meaning or solve the problem. The value of collaborative learning is recognized due to the notion that while explaining a problem to peer learner students can gain conceptual clarity (Damon & Phelps, 1989; Johnson & Johnson,
Teasley (1995) finds that dialogs between students working in dyads are more elaborative than those of students working individually. Many studies have pointed out that collaborative learning is an effective way to enhance students’ learning performances (Finnegan & O’Mahoney, 1996; Johnson & Johnson, 1994; Hohmann, 1997; Nelson, 1999; Miyake, 2006). Interpersonal interaction makes managerial decisions overt (Schoenfeld, 1983), exposes each participant to different perspectives (Miyake, 2006), and efficiently addresses the difficulties that students encounter. Duit, Roth, Komorek and Wilbers (1998) have found that students’ social interactions in science classrooms are positively related to their learning achievement. Students working in dyads generated more elaborative answers than those working individually (Schwartz, 1995; Teasley, 1995). One partner adds a significant contribution to the discourse that develops another person’s idea, and reversely he/she can gain a greater conceptual clarity for himself/herself (Damon & Phelps, 1989).

Collaborative learning is assumed to appeal to both male and female students (Heller & Lin, 1992; Johnson & Johnson, 1993; Kahle & Meece, 1994). However, some studies have clearly pronounced a notable gender difference in collaboration. For instance, females are more likely to hedge, qualify and justify their assertions (Fahy, 2003; Smith, McLaughlin, & Osborne, 1997) while males tend to assert their opinions strongly as facts (Blum, 1999; Fahy, 2002). Females try to avoid conflict and seek support, agreement and suggestions (Johnson & Johnson, 1990; Kahle & Meece, 1994; Maltz & Borker, 1985; Tannen, 1994). In collaborative problem-solving, males tend to monopolize the discussion, being seen as the primary source of help. Yates (2001) found that the males talk more and longer, and they tend to take more turns than females. Taking the gender issue into consideration, we may say that collaborative learning runs the risk of a gender gap in physics learning with a disadvantage for female students.

3.3 Instructional Strategies

In traditional physics classrooms, lecturers demonstrate how they solve a problem and ask the students to model. Students tend to be passive observers with limited opportunities to develop own reasoning and representations. Previous research has demonstrated that simply engaging in some numerical calculations does not imply a corresponding improvement of problem-solving skills (Kim & Pak, 2002; Pride, Vokos & McDermott, 1998). Structured problems-solving is deemed as a way out with regard to enhance students’ performance and conceptual understanding (Maloney, 1994). Webb (1989) found that giving elaborate help stimulates students’ reorganization and awareness of knowledge gaps, and this leads to a more elaborate knowledge-processing. Van Heuvelen (1991) suggested providing students more chances to conduct qualitative reasoning and to construct their own solving strategies.
Heller et al (1992) have demonstrated that students profit from a step-by-step strategy in solving problems independently.

Maloney (1994) summarized that successful students’ problem-solving strategies should contain conscious qualitative analysis of a problem, making a sketch of the problem, restating the problem in one’s own words and a conscious review of equations or theorems that fit the problem. Schoenfeld (1992, 1994) developed a strategy consisting of five episodes. Although Schoenfeld’s strategy originates from solving mathematical problems, it fits the physics problem-solving scenario very well. The episodes refer to read, analyze the problem (analyze), activate relevant knowledge to solve the problem (explore), make a plan (plan), carry out the plan (implement), check the answer (verify). Schoenfeld stressed that one should not dictate strict and linear problem-solving steps. Students need ample room to develop an individual problem-solving strategy. In order to teach them to be conscious users of the episodes, Schoenfeld used some procedural questions such as: Can you make a scheme of this problem? What procedure do you know that could help you? Have you made a plan? Did your solution answer the question? In responding to these questions, students reflect on their use of the episodes and develop self-confidence (Schoenfeld, 1994).

Due to the explicit advantages of instructional strategy, Heller and Lin (1992) conducted a study concerning gender differences in university physics introductory education. They found that female students could perform equally well as male students when they were taught how to use an explicit problem-solving strategy in a cooperative learning environment. It seems that an instruction of explicit problem-solving strategy may help close the gender gap in physics learning. But this claim still needs formal testing.

The aim of this study was to examine the gender difference in both collaborative learning and individual learning with some instructional help. Besides, it aimed at probing whether structuring students’ collaboration through the instructional help contributes to closing the gender gap. Generally, it is hypothesized that individual learning with instructional help produces smaller gender gaps than collaborative learning in physics problem solving.

3.4 Methodology

3.4.1 Participants

The study was conducted in a secondary school in Shanghai, with a sample of 99 students. They were from two eleventh-grade classes taught by the same physics teacher. The school ranked among the top-five best schools in Shanghai. Students in the study were around the age of 17, coming from families with a wide range of occupations, incomes, and educational levels. There were 54 female students and 45 male students. They were randomly assigned to four experimental conditions. Within Condition CL+H and CL, students were randomly paired. Table 3.1 shows the number of participants in the four conditions.
Table 3.1: Experimental Design

<table>
<thead>
<tr>
<th></th>
<th>With Instructional Strategies</th>
<th>Without Instructional Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collaboration</strong></td>
<td>Condition CL+H (n=26): students were required to collaborate on problems with the help of hints</td>
<td>Condition CL (n=24): students were required to collaborate on problems without hints</td>
</tr>
<tr>
<td><strong>Individual learning</strong></td>
<td>Condition I+H (n=24): students were required to work on problems individually with hints</td>
<td>Condition I (n=25): students were required to work on problems individually without hints</td>
</tr>
</tbody>
</table>

### 3.4.2 Procedure

This was a randomized pre- and posttest design study. Prior to the pre-test, there was a 45-minute pre-flight training. The aim of the pre-flight training was to instruct students how to work with the log sheets. First, we asked all participants of all conditions to watch a 20-minute video clip in which a dyad was working a physics problem with the log sheets. In the video tape, two students solved a physics problem concerning forces while discussing their ideas following the episodes of problem solving. After that, all conditions were given a sample problem to practice. During their problem-solving, students in condition CL+H were given a brief instruction about how to use hints to structure their collaboration. Students in condition CL were instructed how to fill in the log sheets jointly. Students in I+H were given an instruction concerning how hints could structure their problem-solving and how to use the log sheets. Students in condition I were also given a sample problem, but didn’t receive any instructional guidance. On the next day, the pre-test was administered to all participants. It took one hour and consisted of two problems. Then, students were assigned into the aforementioned conditions. There were six experiment sessions. In each session, students were asked to solve one moderately-structured physics problem within 50 minutes. Students in all four conditions were given answer sheets. They were required to fill in the five episodes to show how they solve the problems (Table 1). They filled in the sheets for each problem. At the end, students were given a worked out example as the final judge of their solution. On the last day, students were administered a one-hour long post-test.
3.4.3 Instruments

Both pre- and post-test were paper-pencil test, consisting two moderately-structured problems concerning Newtonian mechanics. Problems in experiment sessions, pre- and post-test were selected from the database of the school physics education, with a similar degree of difficulty. Both the pre-test and post-test were given in open-question format. Responses on each episode were given from 0 points (no information) to 5 points (correct and detailed information). The students were required to give information about four episodes: analyze, explore, plan and implement. In total 20 points for each question could be gained. Since students in both pre-test and post-test were asked to solve the problems individually, the final stage, verifying the solution, was not taken into account. Figure 3.1 is the sample problem.

The Spiderman problem:
A child weighing 12 kg fell down from a window at 52nd-floor which is 171.6-meter high. It is immediately spotted by Spiderman and Dr Ock and they act.
The evil Dr. Ock Teaser (90kg) at the bottom of the building starts climbing upwards with his six metal claws to catch the baby. Each claw can execute 200N force to lift him.
Spiderman (65kg) is at the top of the skyscraper which is 198m high. With his hairs gluing on the top of the building, he is flying down to save the baby.
To save the baby, at which velocity must Spiderman fly down from the top?

Figure 3.1 Example of the problem in the experiment

Answer sheet: In each condition, students were required to fill in the answer sheets. Table 3.2 is the sample of the answer sheets. At the end of each experiment session, their answer sheets were collected by the researchers. For condition CL+H and CL, we asked each dyad to work on the answer sheets. There was no requirement who should assume the job of completing the answer sheets.
### Table 3.2 Sample of the answer sheet

<table>
<thead>
<tr>
<th>Starting time: ...</th>
<th>Problem number .....</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Read &amp; Analyze</td>
<td>Answer:</td>
</tr>
<tr>
<td>Make scheme or diagram</td>
<td></td>
</tr>
<tr>
<td>2. Knowledge</td>
<td>Answer:</td>
</tr>
<tr>
<td>Write down the equations or theorems you need</td>
<td></td>
</tr>
<tr>
<td>3. Plan</td>
<td>Answer:</td>
</tr>
<tr>
<td>Work it out in a plan</td>
<td></td>
</tr>
<tr>
<td>4. Implement Plan</td>
<td>Answer:</td>
</tr>
<tr>
<td>Show your calculations</td>
<td></td>
</tr>
<tr>
<td>5. Verify Answer</td>
<td>Answer:</td>
</tr>
<tr>
<td>How did you check your answer?</td>
<td></td>
</tr>
<tr>
<td>Ending time: .......</td>
<td>Comments on the process:</td>
</tr>
</tbody>
</table>

From the answer sheets the researchers gathered information about the problem-solving process in the four conditions: how many problems were solved correctly, which information students gave about the episodes of a problem, and the time of start and completion of a problem.

**Videotapes and observations:** More qualitative process information was gathered by making videotapes during the program of one dyad in condition CL+H and one dyad in condition CL. The students’ conversations were videotaped and transcribed. Two students in condition I+H and condition I were asked to verbalize their problem solving activities while they were videotaped. Besides, one of the researchers observed the students in the four conditions and made field notes of the nature of their learning activities.

**3.4.4 Hints:**

In this research project the episodes of Schoenfeld’s approach (1992) serve as stepping stones for problem-solving, and are used to structure students’ learning processes. Students were required to work according to a script on the five episodes. The hints that go with each episode were on cards and numbered sequentially from 1 to 5. The hints consisted of a text that described the main topics in an episode and a diagram that depicted the problem situation.

In both condition CL+H and I+H, the hints were put upside down in front of the
students. There were no unbending rules using the hints. As aforementioned, Schoenfeld stressed the non-linear and flexible use of problem-solving strategy. We let the students themselves make the decision about whether to read the hints and when to read the hints. Figure 3.2 is the sample of hints for the *Spiderman* problem.

**Hint 1**
**Read and Analyze Problem**

It is necessary to draw a picture to illustrate all the forces applied on Dr. Ock, baby and Spiderman. And imagine that at one point in the sky the baby will be caught by Dr. Ock.

**Hint 2**
**Recall Prior Knowledge**

Write down the equations for the three regarding:

a. Distance they move

\[ S_{\text{baby}} = S_{\text{total}} \]

b. Force applied on them

\[ F = m \cdot a \]

F = \text{Force}
\[ a = \text{Acceleration} \]

F \downarrow = m_{\text{oxygen}} \cdot g

F \downarrow = m_{\text{box}} \cdot g
Hint 3
Make a Plan

Solve:
- Force applied on Dr. Ock
- Acceleration of Dr. Ock
- Time Dr. Ock uses to catch the baby
- Distance Dr. Ock or the baby moves
- Distance Spiderman moves
- Initial velocity Spiderman should have

Hint 4
Implement the Plan

Solve the following variables:
- \( t = ? \)
- \( S_{\text{baby}} = ? \)
- \( S_{\text{system}} = ? \)
- \( V_0 = ? \)
- The solution is ...

Hint 5
Verify your Answer

- Are you sure that your answer is correct?
- Are you sure that your solution is the most effective?
- Have you got any other methods to solve the problem?

Figure 3.2 Hints for students in condition CL+H and I+H with the problem in Figure 3.1
1. Problem survey (Read, Analyze)

Students are required to verbalize the problems to identify the known and unknown information of the problem, and determine a general approach that is appropriate to this situation, such as what kind of concepts and principles will be useful in solving this problem. The result of their discussion can be a rough picture showing the objects, their motion and direction.

2. Active Knowledge (Explore)

Students are asked to translate their sketch into a scientific description with a diagram. In the diagram they define variables to calculate desired quantities. They write down the formula that may help to solve the problem. The hints may be used only after the discussion.

3. Make a Plan (Plan)

After making a scientific description, students are asked to make a solution plan individually. This plan should involve the steps in the equations and rough estimates of the outcome. Then they are asked to put their plans together to compare. It is not necessary that there must be consent or one must follow the other's plan. Comparison of the solution plan simply makes students aware that more than one solution is possible. They may use the hint to check if they are on the right track or they may correct their solution plans if necessary.

4. Carrying out the Plan (Implement)

Students are asked to translate their own plan into a series of appropriate mathematical actions by substituting the numerical values into a formula and to solve the final equation. It is necessary for them to check regularly whether they are meeting their targets and revise the plan accordingly.

5. Control of the Answer (Verify)

Based on their answers, students are encouraged discuss their solutions. When they have got the same answers, they are asked to retell their solving process and check whether they have really arrived at the right solution. If their answers are different, they should determine whose is correct or complete. They are also asked to reflect on what they had learnt for future problems and tasks, and what kind of strategies are more efficient and can be adopted later on.

3.5 Results

3.5.1 Implementation of the treatments

Ninety-nine students took part in the introduction course, the pretest, six experiment sessions and the posttest. Students in Condition CL+H and CL were randomly paired. They
seemed to spend more time on the task than did those in other conditions. In each session, they asked for an extension to finish their discussion. Although the number in our sample was limited, reviewing their answer sheets can offer a general picture about the problem solving process. From their answer sheets, we found that CL+H and CL had some traits in common. Firstly, in both conditions, the female-female dyads generated the most detailed descriptions. Their descriptions were organized in an orderly fashion. Within the dyad, the female students took turns to fill in the answer sheets. None of the dyads skipped any of the episodes. In contrast, the descriptions of the solution process on the answer sheets of the male-male dyads were less orderly. One dyad seemed to “doodle” the answer sheets from the first experimental problem till the last. Neither of the dyads filled in the episodes completely. Secondly, we found that the female-female dyads gave the least pictorial descriptions in both conditions. Female students tended to represent problem information verbally. Very few pictorial representations were found in the female-female dyads’ answer sheets.

Condition CL+H and CL were also different in the following aspects. Generally, the answer sheets of Condition CL+H were more detailed and more neatly organized than those in Condition CL. In Condition CL, dyads tended to skip the first and the last episode, namely, analyzing the problem and reflecting on the answer. By contrast, dyads in CL+H filled in each episode with detailed description. We noticed that, in condition CL, the mixed-gender dyads were less likely to take turns filling in the answer sheets. The student who filled in the answer sheets for the first problem would stay with the task until the last experimental problem. Normally it was the male student that assumed the task of completing the answer sheets. But in condition CL+H, some female students filled in the answer sheets.

There were fourteen female students and ten male students in Condition I+H. In each session, there were always two or three male students asking to hand in their answer sheets earlier, but no female student asked to leave early. The male students also asked for the possibility of getting problems for the next experimental session. Looking into their answer sheets, we found that females gave the most detailed and orderly accounts of their problem-solving processes among all conditions. In contrast, males in Condition I+H were more likely to use pictorial presentations to illustrate their solutions. When reading a problem, they tended to convert the verbal information into schemas. Some of their schemas did express a plethora of words in one economical format, but some were illustrated too simply and randomly, running the risk of blurring the logical relationships among variables. Moreover, all female students have used the hints during the experiment sessions, but there were three male students that never touched the hints in front of them.

In Condition I, there were eleven females and fourteen males. Males seemed to be the fast problem-solvers. In each session, half of them spent less than fifteen minutes on each problem. Very few male students stayed in the classroom till the session ended. The analyses of students’ answer sheets showed that males’ answer sheets did not look very
orderly, and were pictorial and economical in nature. As for females in this condition, we noticed that a lot of episodes of their answer sheets were left blank. Their problem analyses and solutions were neat, but often lacked logical organization. Males in Condition I seemed to be the “rash” problem-solvers, handing in their answer sheets quickly.

### 3.5.2 Learning Achievement

In order to answer the research questions, we looked into student’s pre and posttest learning achievement. The means and standard deviations of students’ pretest and posttest scores are shown in Table 3.3.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Females (n=15)</th>
<th>Males (n=11)</th>
<th>Total (n=26)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition CL+H</strong> (Collaboration with hints)</td>
<td>8.27 (8.38)</td>
<td>7.91 (6.20)</td>
<td>8.12 (7.40)</td>
</tr>
<tr>
<td><strong>Condition CL</strong> (Collaboration)</td>
<td>8.40 (7.23)</td>
<td>11.90 (10.05)</td>
<td>9.80 (8.45)</td>
</tr>
<tr>
<td><strong>Condition I+H</strong> (Individual learning with hints)</td>
<td>10.67 (8.10)</td>
<td>8.12 (8.22)</td>
<td>9.39 (8.01)</td>
</tr>
<tr>
<td><strong>Condition I</strong> (Individual learning)</td>
<td>5.78 (6.94)</td>
<td>9.38 (8.20)</td>
<td>8.08 (7.82)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>8.39 (7.68)</td>
<td>9.36 (8.08)</td>
<td>8.83 (7.84)</td>
</tr>
</tbody>
</table>

*indicates a significant difference with females in Condition I.*

For students’ learning achievement, we first checked whether there was a difference in the female and male students’ pretest performances between the conditions. Analysis of variance (ANOVA) with two “conditions”(collaboration or individual learning; with or without hints) and “gender” as the independent variables, and “pretest” as the dependent variable was employed. It turned out that there were no main effects for “gender” \(F_{(1,91)}=.52, p=.47\), nor...
for the “condition” \( (F(1,91) = .22, p = .64) \), nor for the hints condition \( (F(1,91) = .03, p = .87) \). There were no two-way or three-way interaction effects for pretest results, either.

This study examined the gender differences in collaborative learning and the use of hints and its effects on students’ learning achievement. First, with students’ posttest scores as the dependent variable, pretest scores as the covariate, the analysis of covariance (ANCOVA) test was performed on the two independent variables: collaborative learning or individual learning, with hints or without hints. The analysis showed that both collaborative learning and the use of hints had a significant main effect with \( F(1,91) = 6.42, p < .05 \) and \( F(1,91) = 4.32, p < .05 \), respectively. There was also a significant interaction effect between collaborative learning and the hints condition, \( F(1,91) = 4.70, p < .05 \).

Next, to examine the gender difference in the conditions, we looked into the interaction effect of variables: collaborative learning or individual learning, with or without hints, and gender. It was found that the three-way interaction effect (collaborative learning*hints*gender) was significant, \( F(1,91) = 4.04, p < .05 \) This indicated that gender might play a role in some conditions. In order to gain an insight into the gender difference, we carried out a pair-wise comparison with Bonferroni adjustment.

For female students, those in condition CL+H outscored those in condition I significantly, \( F(1,24) = 12.52, p < .01 \). Females in condition CL also did better than their counterparts in condition I, \( F(1,24) = 8.51, p < .05 \). So did females in condition I+H. They outscored females in condition I, \( F(1,24) = 16.29, p < .01 \). But for male students, the difference between the conditions were not significant, \( F(3,45) = 1.75, p > .05 \).

Within each condition, we examined the gender differences. In both condition CL+H and CL, male students outscored female students. But only the difference in condition CL was significant, \( F(1,24) = 6.48, p < .05 \). In condition CL+H, there was no significant gender difference in their posttest, \( F(1,25) = 3.26, p > .05 \). In condition I+H, female students seemed to outscore male students. But the difference was not significant, \( F(1,22) = 1.24, p > .05 \). In condition I, we found a significant gender difference with female students at a disadvantage, \( F(1,24) = 10.87, p < .01 \).

With respect to the research question, whether there is gender difference moderated by collaborative learning or hints, in our experiment we have found a gender difference in learning performance on posttest in two conditions: condition CL and condition I. In both conditions, female students were at a disadvantage. It is worth mentioning that within these conditions female and male students’ scores were not significantly different for the pretest. But after six experiment sessions there appeared to be a significant difference. But when students learning individually or collaboratively with hints at hand, there was no significant gender difference in learning achievement.
3.6 Conclusion

It seems to be a global problem that physics addresses the largest gender gap in school practices. Males tend to outscore female students in physics (Sadker & Sadker, 1994), and females drop out of physics-related majors at a higher rate than do males (Garratt, 1986). In high schools, males outnumber females in scientific subjects, and physics shows the most problematic gender gap (Lorenzo, Crouch & Mazur, 2006). It is well established that both collaborative learning and individual learning with some instructional help are more effective in improving students’ learning performance than individual learning alone. But research into whether they are equally effective for male and female students is rare.

The aim of this study is twofold. First, it examines the gender difference in these two heuristic methods that are frequently used in current classroom practice. We found that on the pretest there was no significant difference between students in four conditions. But after six experiment sessions, in condition CL and condition I there appeared a significant gender difference. This finding is in direct contradiction to much of the previous literature that backs up cooperative learning for smoothing out the gender gap (e.g. Walker, 1997, Chase & Okie, 2000). Our analyses of students’ answer sheets and the case study provided some information about the likely causes. First of all, female and male students seemed to have different ways of representing information. Males were more likely to use pictures to represent the relationship of variables, while females tended to describe them in words. Second, female students’ problem-solving process tended to be influenced by their partner gender. The female-female dyads seemed to get involved in problem-solving task more than females in the mixed-gender dyads. In condition CL, we found that the task of completion of the answer sheets was always assumed by the male students.

In condition I+H (individual learning with hints), the difference between female and males’ learning achievement was not significant. It seems that individual learning with hints may help to smash the gender gap in physics problem-solving in particular. Hints help students discover their misconceptions and organize their thinking. Our analyses of students’ answer sheets in this experimental condition showed that females’ problem analyses were logical and accurate. The females’ answer sheets showed that they were actively involved in hint reading. Hints were used as just-in-time instruction promoting females’ internalization of knowledge. Learning with the use of hints may make female students feel free to try and develop their own methods. The observation of the experiment sessions suggested that females paid more attention to the hints than did male students.

The second aim of the study was to explore the possibility to structure students’ collaborative learning through hints. We provided each dyad in condition CL+H (collaborative learning with hints) five hints that were compiled on the basis of Schoenfeld’s problem-solving strategy. Students were asked to read the hints on self-selection. In comparison with condition CL (collaborative learning without hints), we found that there was no significant
difference between female and male students. Structuring students’ collaborative problem-solving through well-designed hints seemed to be a way out to alleviate the gender gap in physics learning. With regard to the two instructional methods, collaborative learning and individual learning with some help, we may conclude that learning from a peer learner might increase gender difference in learning performance, while learning individually from instructional materials might close the gender gap. If we intend to smash the gender gap in collaborative learning, we may try providing some instructional help for the dyad or group. This may give the female students more confidence in developing own solving strategies.

Students in Condition I did not receive any help from peer learners, the teacher or from instructional materials. During the four-week experiment they solved problems individually. Giving students problems without providing any help is used in most physics classrooms. Students usually receive home assignments from the teacher and are asked to solve the problems individually without any help. Teachers commonly believe that the more exercises students do, the higher the scores they will get and the greater their improvement in problem-solving skills. From our study we’ve seen that individual learning without any help is the least effective way for female students. In the study, female students did not significantly lag behind male students in the pretest. But after the six experiment sessions, the gender difference was evident. Males scored significantly higher than females in the posttest.

These findings shed light on current research on science teaching and practical classroom instruction. In traditional whole-class instruction, teachers tend to treat female and male students in a uniform way. Males contribute noticeably more than females by raising their hands or speaking up in class. In contrast, females receive scant attention due to their non-assertiveness. Both education researchers and practitioners need methods that tap into the potential of females so as to narrow this gender gap. Therefore, we propose three suggestions for secondary school physics instruction.

\textit{Suggestion 1}: Design instructional help for students’ problem-solving learning and give the girls more chance to learn with the help of hints.

\textit{Suggestion 2}: Prompt students to collaborate with each other in problem-solving, but plan carefully to avoid the male monopolization in discussion.

\textit{Suggestion 3}: Never let female students face the problem without any aid.

\section*{3.7 Discussion}

While we believe strongly in the validity of our study, we do recognize its limitations. One is the sample size. Examination of students’ answer sheets indicated that the interaction might vary with gender composition in the collaborative conditions. Some previous research has also suggested that simply grouping students does not ensure high learning achievement.
Some have claimed that mixed-gender pairing affords the opportunity to close the gender gap (Slavin, 1995; Johnson & Johnson, 1994), while some have pointed out that single-gender grouping is more suitable for female students (Siann, Durndell, Macleod & Glissov, 1988; Barbieri & Light, 1992). In the current study, there were five mixed-gender, five female-female and three male-male dyads in condition CL+H, and five mixed-gender dyads, five female-female and two male-male dyads in condition CL. We have noticed that, in condition CL (collaboration without hints), the pretest scores of females in the mixed-gender dyads were almost the same as their male partners, but in the posttest they markedly lag behind. Similarly, in condition CL+H (collaboration with hints), males in the mixed-gender dyads outsored their female partner in the posttest. However, due to the limited number of dyads in both conditions, it was inadequate to statistically examine the difference of dyads gender composition. We suggest researchers to explore the differences in mixed versus single-gender collaboration. If this difference could be detected, it would be interesting to test whether students’ problem-solving process was influenced by their partner gender. In the future research, we may further to explore how to relate these differences in problem-solving process with students’ learning achievement.

Another limitation was the scope of the program in our study. Because this program lasted only for six sessions and tested only the students’ academic achievement, we were unable to assess the students’ development of problem-solving skills in science. In future, it would be necessary to conduct a more extensive study, testing students’ problem-solving skills as they develop in different cooperative and individual settings. In this regard, the delay posttest design is favored.

Finally, these differences between female and male students in terms of self esteem and communication style in secondary school science education are also evident in Western nations (Sanders & Nelson, 2004). But we are still interested in knowing whether the results of this study really can be generalized to secondary schools not only in China, but also in other countries.