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Gender effect of multiple solution method in high school physics learning

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Abstract: Physics instruction is difficult, especially for advanced knowledge acquisition. In the literature, many effective improvements on physics instruction were reported. On the other hand, multiple solution methods were considered as effective pedagogy for advanced knowledge acquisition, but there were only limited controlled studies on such methods. Therefore, the original goal of this study was to design a multiple solution method and perform quasi-experiments to investigate the effectiveness of the multiple solution method. The results of the experiments in this study indicated that no improvement was obtained with the multiple solution method. However, investigation of the experiment data and learning behavior of the subjects revealed that there was presumably a gender effect of the multiple solution method, a gender effect opposite to the ordinary one. Although the confirmation of the gender effect requires further investigation, this finding is interesting in that it may help point out a new direction to improve physics instruction design.

Keywords: Multiple Solution Method, Physics Instruction, Advanced Knowledge Acquisition

1. Introduction

Physics is considered a difficult subject for most of students around the world. Therefore, improvements of physics instruction are desirable objectives to be pursued. In this study, a multiple solution method was designed and experimented to investigate its effectiveness in improving physics instruction.

The difficulty of physics instruction was partly reflected in the results of physics education. Halloun and Hestenes [1] reported that contemporary physic instruction imparted only limited physics knowledge to college students in the United States. However, much effort has been devoted to improve physics instruction. Among them, interactive engagement methods are known to be productive. The improvement of normalized learning gain of interactive engagement methods is about two standard deviations above that of conventional instruction [2]. That is, interactive engagement methods are an answer to Bloom's two sigma problem [3]. By conventional instructions, Hake classified them as instructions that relied on "*passive-student lectures, recipe labs, and algorithmic-problem exams*," and by interactive engagement methods as those "*designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on and hands-on activities which yield immediate feedback through discussion with peers and/or instructors*".

Instructional tasks of a physics class typically include concept lecturing, demonstration of problem solving, and student problem-solving activities, and there are effective interactive engagement methods for implementing each of the three tasks. For example, Peer Instruction uses the ConcepTests pedagogy to engage students by questions and by peer discussion during lecturing [4]. Collaborative groups help students attaining better problem solutions than individual problem solving, even for the students with best learning performance [5] [6]. Both of these well-established instructional methods belong to interactive engagement ones [2]. Additionally, it was shown that the more of the portions of the instructional tasks employed interactive engagement methods, the higher the normalized learning gains were obtained [7]. Many of the works, such as Peer Instruction and collaborative groups, are widely adopted and their improvement are continuously made [8] [9].

Despite the success of interactive engagement methods, it is still worthy to explore pedagogies that are potentially beneficial to help students acquire advanced knowledge. As it was pointed out, students may learn problem-solving algorithms without correctly acquiring the core concepts of physics under traditional physics instruction [8]. Students need to acquire advanced knowledge to avoid such shallow understanding of physics. In the literature, cognitive flexibility theory contended that advanced knowledge acquisition is different from introductory learning and thus the effective pedagogies are potentially different [10]. The arguments of cognitive flexibility theory include tendencies of oversimplification and single representations that miss important facets of complex concepts in introductory instruction. Such discrepancies in introductory instruction may lead to difficulties in advanced knowledge acquisition. Accordingly, exposing students to adequate complexity is beneficial for acquisition of advanced knowledge. In fact, Heller and Hollabaugh [6] found that although their context-rich problems were more complicated for students than standard textbook problems, these problems are beneficial for student learning. Recent studies also support the benefits of exposing students to multiple representations of complicated science concepts [11] [12]. Therefore, simplification is not necessarily beneficial for learning from the perspective of advanced knowledge acquisition.

To help student acquire advanced knowledge acquisition, we explore the pedagogy of exposing students to multiple solutions of a physics problem, which is a multiple solution method for student problem-solving activities. Although multiple solution methods increase the complexity of learning of problem solving, such methods help students look at the same problems from different perspectives. Thus, multiple solution methods are potentially beneficial for advanced knowledge acquisition. Theoretically, the arguments of cognitive flexibility theory and cognitive apprenticeship also support multiple solution methods, though there are few controlled studies on the effectiveness of such methods [13]. The success of interactive engagement methods makes it more sensible to investigate whether multiple solution methods will further improve the effectiveness of interactive engagement methods. Thus, the original goal of this study was to investigate whether integration of our multiple solution method with an interactive engagement method will produce additional learning benefits over the interactive engagement method alone. The interactive engagement method used in this study was collaborative groups for student problem solving activities. However, no improvement was observed in the results of our experiments. Thus, the main contribution of this study was to investigate the potential reasons why no improvement was obtained by our multiple solution method. It turned out that a presumable gender effect was found, as reported later in this paper.

2. Implementation of Multiple Solution Method

In typical physics classes, many physics problems come with multiple solutions. It is natural that multiple solutions of a problem will come out from a class of students working on the same problem set. Thus, exposing students to multiple solutions of a physics problem is natural when multiple student solutions emerge. Alternative student solutions may arouse curiosity and provoke reflection among students. This is especially true when the students are highly motivated learners. During implementation of our multiple solution method, the whole class was divided into collaborative groups and each group was asked to work out a solution of a given problem. After completion of group solutions, all the group solutions were projected at a center monitor. The instructor commented on the group solutions and then gave students a period of reflection time. More implementation details are described in the following subsections.

2.1. Collaborative Group Problem Solving

As stated previously, interactive engagement methods are effective physics instruction methods and there are several interactive engagement methods for different instructional tasks [2] [7] [14]. For student problem-solving activities, collaborative groups are a common and effective pedagogy. Furthermore, among various physics instructional tasks, the most intuitive application target of multiple solution methods is student problem solving. Therefore, collaborative groups were used as a baseline case to test the effectiveness of our multiple solution method.

The strategy used in student group formation of this study is largely according to the principles of Student Teams-Achievement Division [15]. The number of group members is 5 or 6. Group leaders are chosen from top learning performance students and are in charge of coordinating group discussion and reporting the final solution of their groups. Other students were evenly distributed among all groups according to their previous learning assessment scores in physics.

2.2. Adoption of Digital Pens

Multiple solution methods can be implemented without using modern technological tools. However, instruction time can be saved if proper technological tools are used. In this study, we implement the multiple solution method with Anoto's *digital pens* and *digital paper*, which appear to be and are also used the same way as ordinary pens and paper. However, each digital pen is equipped within it a tiny camera to capture where and what is written on digital paper with the pen. Dots invisible to naked eyes were printed on ordinary paper to become digital paper and helped the digital pen to accurately locate the position of itself on digital paper. Digital pens also equipped with a Blue Tooth wireless communication component to transmit the captured data to a

PC. Thus, student answers can be collected without taking additional time and multiple student solutions can also be displayed without taking additional transcription time. This use of digital pens and digital paper is significant in helping retain the same portions of instructional time in lecturing and student problem solving, whether the multiple solution method was used or not. It did not substantially change the class dynamics either.

3. Two Phases of Experiments

To investigate whether our multiple solution method will produce additional benefits for collaborative group problem solving, two phases of experiments were planned and conducted. Pretests and posttests were taken to measure the effects of the treatments in all the experiments. The goal of the first phase was to confirm the effectiveness of our implementation of collaborative group problem solving (compared with traditional instruction). The second phase was to compare student learning performance between collaborative groups alone and collaborative groups with multiple solution method. Before all the experiments, the subjects of this study had been taught in a traditionally way for a long time. Therefore, we also want to assure that proper implementation of collaborative groups should be adopted in the second phase and all the adjustments in implementation of collaborative groups should be completed in the first phase. All the experiments were videotaped to allow subsequent analysis and implementation adjustments.

In fact, two experiments were conducted during the first phase. The first experiment in the first phase produced results that were contrary to the literature. That is, students learning in the traditionally way outperformed students in the collaborative groups. After reviews, it was found that students chatted more often than their previous classes in the collaborative groups, except the students seating right before the video camera. This finding suggested that the video camera served as a reminder of classroom order for those students. To help rectify the classroom order problem, video cameras were setup for each collaborative group subsequently. The instructor also took more attention in classroom management in subsequent classes. In the second experiment of the first phase, the classroom order problem was eliminated and students in the collaborative learning group outperformed students in the individual learning group, as described in a subsequent subsection.

3.1. Participants

Two eleventh grade gifted classes from a Taiwan national high school were the subjects of this study. The student numbers in the two classes were 44 and 37, respectively, with a total of 81 students. The high school was among the top two in the north eastern part of Taiwan and these subjects belonged to those with best learning performance in this school. The subjects were mostly highly motivated learners according to a three-month observation. One of the two classes served as the controlled group, consisting of 44 students (31 males, 13 females), and the other served as the experimental group, consisting of 37 students (14 males, 23 females). The class served as the controlled group remained the same role in all experiments. Therefore, the controlled group was first taught traditionally (the first phase) and then by using collaborative groups (the second phase). The experimental group was first taught in collaborative groups alone (the first phase) and then in collaborative groups with multiple solution method (the second phase). The average scores of summative assessment in physics of the two classes were not statistically different before the experiments. The instructor of the two classes was the same.

3.2. Experimental Period and Learning Materials

Each experiment lasted for two weeks of instruction and there were four class hours in one week. This experimental period covered exactly one lesson topic. After enhancement of classroom management, the physics topic taught in the experiment of the first phase was gravity. The topic in the second phase was planet and satellite movement. Pretests and posttests were consisted of ten problems selected from a test banks published by a well-known Taiwan high school textbook publisher.

3.3. Collaborative group Problem Solving vs. Individual Problem Solving

After enhancing classroom management, the experimental group outperformed the controlled group after the treatment. Each of the numbers of pretest and posttest scores in Table 1 denotes the mean of number of correct student answers in the test of the corresponding group. The largest possible value of these numbers is ten. Learning gain of each student was calculated according to the following formula:

$$\frac{posttest - pretest}{10 - pretest}$$

The numbers in the parentheses denote the standard deviations. Accordingly, the learning gain of the experimental group was about one standard deviation above that of the controlled group. There are no significant statistical differences (t-test) between the pretest scores in the two groups but there are significant statistical differences in the posttest scores and learning gains. This result is consistent with the results of Hake's study [2].

Table 1. *Collaborative group vs. individual problem solving*

	N	pretest	posttest	learning gain
Individual	44	3.296 (1.812)	6.227 (1.655)	0.457 (0.135)
Group	37	3.081 (1.479)	7.162 (1.482)	0.607 (0.166)
				***p<0.001

3.4. Multiple Solution Method Treatment vs. no Treatment

The t-test of pretest scores shows that there is significant statistical difference between the two groups, thus t-test of posttest scores is unable to tell whether there is significant performance difference between the two groups. Additionally, Levene's test indicated that the variance of the two groups were not the same. Thus, ANOVA was not applicable either. Accordingly, pretest scores were used as a covariant variable to test the statistical differences (ANCOVA) between learning gains and delayed learning gain. To the opposite of our expectation, the multiple solution method did not improve collaborative groups, as shown in Table 2. On the contrary, the learning gain of collaborative group with multiple solution method was smaller than that of collaborative group alone, though the difference was not statistically significant. This result led us to conjecture that perhaps the multiple solution method would produce benefits only in longer terms. Hence a delayed test was given one week later. However, the results of the delayed test between the two groups remained no significant difference. To the opposite of our conjecture, the difference enlarged slightly.

After carefully examining the posttest scores and delayed test scores of each individual student, it was found that the absolute difference between the posttest and the delayed test score of each student was one or zero except for three students. That is, the distribution of differences between posttest scores and delayed test scores were rather uniform among the students. Note that there is improvement in the delayed test scores over the posttest scores in the controlled group, but the delayed test scores in the experimental group declined.

Table 2. *Multiple solution method (MS) vs. No multiple solution method (No MS)*

	N	pretest	posttest	delayed test	learning gain	delayed learning gain
No MS	44	0.841 (1.077)	4.318 (2.154)	4.386 (2.325)	0.365 (0.256)	0.373 (0.275)
MS	37	0.297 (0.661)	3.595 (1.950)	3.568 (2.141)	0.333 (0.225)	0.327 (0.255)
					$p>0.05$	$p>0.05$

The improvement in the delayed test scores of the controlled group could be explained by the reviewing effect of the posttest, but the reasons of the degradation of delayed test scores of the experimental group was puzzling. Since many studies showed that gender was important factor in the differences of physics learning performance [7] [16], analysis of gender effect in the experiment was carried out as an afterthought to seek out the reasons of the degradation of delayed test scores in the experimental group.

3.5. Gender Effect of Multiple Solution Method

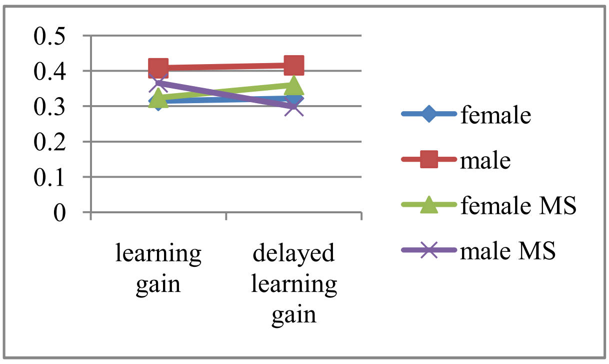

Figure 1. *Differences between learning gains and delayed learning gains under the influence of genders and the treatment of multiple solution method*

The data shown in Figure 1 is obtained by dividing the data in last two columns of Table 2 according to genders. There are gender gaps in the learning gains whether the treatment of multiple solution method was used or not. The gender gaps in the learning gains are consistent with the literature. However, the gender gap shrinks under the influence of multiple solution method, but the average learning gain of all students becomes smaller according to Table 2.

Interesting results were found in the data of delayed learning gains. In the controlled group, the delayed learning gains of both male and female students were slightly larger than their relevant learning gains. As stated previously, the increase of delayed learning gain could be explained by the reviewing effect of the posttest and this observation was consistent in both genders in the controlled group. But in the experiment group (the treatment of multiple solution method, denoted by MS in the legend), the explanation of the reviewing effect of the posttest was violated by the male student data. Furthermore, the increase of delayed learning gains of female students in the experimental group was larger than the increase of delayed learning gains of female students in the controlled group.

This gender effect of the multiple solution method leads us to look for the reasons from student learning behaviors. After reviewing the recorded video data of the experiment, it was found that when multiple solutions were displayed at the center monitor, most male students tended to ponder over the alternative solutions but most female students tended to transcribe all the alternative solutions in their notebooks. Thus, the difference in learning behaviors seemed to be the reason of the observed gender effect. Perhaps it was due to no further practice after pondering on alternative solutions, the male students tended to mess things up in the delayed test slightly (there was only little differences in posttest scores and delayed test scores). In fact, in the interviews with male students, they were not aware of their performance degradation. However, the null hypotheses of several statistical tests (t-test against several parameters, ANCOVA with several parameters as co-variants) were not rejected partly due to the unbalanced student numbers in both genders, though the tendency was observed. Thus, confirmation of the gender effect and the explanation required further investigation.

4. Concluding Remarks

In physics instruction, advanced knowledge acquisition is desirable and multiple solution methods are potentially beneficial for this. However, there seems to be gender effect on the multiple solution method of this study. The different learning behaviors in the two genders were presumable to account for the gender effect, but further investigation is required to confirm the accountability. Intuitively, multiple solution methods should be beneficial for highly motivated and high performance students, such as the subjects in this study. If learning behavior (simply pondering versus simply transcribing all possible solutions) is really the intervening factor, simply pondering should be discouraged when such a multiple solution method is used. Otherwise, relevant enhancements should be investigated. For example, similar problems may be given for practice to investigate whether the downside effect of pondering can be removed. This finding is important in that deep thinking (pondering) is usually considered as beneficial for physics learning.

Another reason that no significant difference was observed whether the treatment of multiple solution method was used could be attributed to the goal of the tests. The problems in the pretests, posttests, and delayed tests are all the same. Thus, what was measured was whether the subjects were able to solve the same problems. But the reason that pondering is considered beneficial for learning should be relevant to whether the subjects are able to solve similar but different problems. That is, if transfer of learning was the goal of the tests, there might be significant difference.

Nonetheless, no matter what the reasons of the presumable gender effect are, multiple solution methods deserved further investigation, as it may help improve subsequent design of physic instruction. What is confirmed in this study is the effectiveness of the pedagogy of collaborative group problem solving. After the experiments, the instructor continued using the pedagogy of collaborative group problem solving till the end of the semester for the two classes. The summative assessment scores of the two classes greatly outperformed students in other counterpart classes. However, note that high motivation is an important factor for the success of our implementation of collaborative group problem solving.

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References

[1] Halloun, I. A., & Hestenes, D. (1985). The initial knowledge state of college physics students. *American journal of Physics*, *53*(11), 1043-1055.

[2] Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American journal of Physics*, *66*, 64-74.

[3] Bloom, B. S. (1984). The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher, 13*(6), 4-16.

[4] Mazur, E. (1997). *Peer instruction: A user's manual*. Prentice Hall, NJ.

[5] Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. *American Journal of Physics*, *60*(7), 627-636.

[6] Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics, 60*(7), 637-644.

[7] Lorenzo, M., Crouch, C. H., & Mazur, E. (2006). Reducing the gender gap in the physics classroom. *American Journal of Physics*, *74*, 118-122.

[8] Crouch, C. H., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69*, 970.

[9] Zingaro, D., & Porter, L. (2014). Peer instruction in computing: The value of instructor intervention. *Computers and Education*, 71, 87-96.

[10] Spiro, R.J., Coulson, R.L., Feltovich, P.J., & Anderson, D. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. In V. Patel (ed.), *Proceedings of the 10th Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Erlbaum.

[11] Ainsworth, S. (2008). The educational value of multiple-representations when learning complex scientific concepts. In J. K. Gilbert et al. (eds.) *Visualization: Theory and practice in science education*, Springer Netherlands, 191-208.

[12] Wong, D., Poo, S. P., Hock, N. E., & Kang, W. L. (2011). Learning with multiple representations: an example of a revision lesson in mechanics. *Physics Education*, *46*(2), 178.

[13] Große, C. S., & Renkl, A. (2006). Effects of multiple solution methods in mathematics learning. *Learning and Instruction*, *16*(2), 122-138.

[14] Pollock, S. J., Finkelstein, N. D., & Kost, L. E. (2007). Reducing the gender gap in the physics classroom: How sufficient is interactive engagement? *Physical Review Special Topics-Physics Education Research*, *3*(1), 010107.

[15] Slavin, R. E. (1978). Cooperative learning. *Review of Educational Research, 50*(2), 315-342.

[16] Kost, L. E., Pollock, S. J., & Finkelstein, N. D. (2009). Characterizing the gender gap in introductory physics. *Physical Review Special Topics-Physics Education Research*, *5*(1), 010101.