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The Effect of a Problem-oriented Teaching Method on University Mathematics Learning

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ABSTRACT
In mathematics learning, it is important to solve problems. However, it is not easy for students to design and implement an effective problem-solving plan. Therefore, we propose a problem-oriented teaching method based on the existing literature. The purpose of this study is to investigate the influence of this problem-oriented teaching method on the learning effectiveness of students. Research subjects were part of two classes that were randomly selected from a public university in China; one was the experimental group that was subjected to the problem-oriented teaching method, and the other was the comparison group that was subjected to the traditional teaching method. In this study, at the beginning and end of the semester, the experimental and control groups were assessed. The results of the empirical analysis show that the problem-oriented teaching method was more effective at improving mathematics achievement and reducing the differences in scores between urban and rural students than traditional teaching methods. Suggestions and implications for teaching are also proposed for mathematics educators and mathematics education researchers: teachers should not only ask questions but also guide students to ask questions.

Keywords: problem-oriented, problem-solving, scores differences between students in urban and rural, mathematics education, mathematics learning

INTRODUCTION

Mathematics is not only the mother of all science but also the foundation of all scientific research. Mathematics, including the use of abstraction and logical reasoning, the calculation of numbers, and the analysis of things changed rules, is often described as a formal science that studies concepts using symbolic language. Today, mathematics is spanning various sciences and applies in many professions and disciplines. It is taught as a mandatory compulsory course in primary and secondary schools in many countries.

Therefore, for each student, the importance of mathematics is self-evident. However, it is not easy for some students to learn mathematics well. The reason for this phenomenon lies in the students' impression of the subject of mathematics and mathematics learning methods. When they first encounter mathematics in a classroom, most students observed that mathematical problem-solving processes are step by step, starting from simple conditions and resulting in a complex result. Then, they feel that mathematics is a complicated subject that is difficult and abstract (Schwartz, 2000, quoted by Dodeen, Abdelfattah, Alshumrani, 2014).

The possible reason for this feeling is that current mathematics education often pays more attention to technical issues, such as formulae and procedures. Conversely, understanding, presentation, and reasoning are not given sufficient attention (Cunningham, 2004). Such students are passively trained as well-practised formula users and do not really understand the formulae. As the old Chinese saying states, "I know it, but I do not know why."

However, to learn mathematics, it is still necessary to learn how to solve problems (Contreras, 2005; Felmer, Pehkonen & Kilpatrick, 2016; Perdomo-Díaz, Felmer, Randolph, & González, 2017). This is one teaching objective that has long been regarded as a very important step in the teaching process. The teaching method focusing on problem-solving has been a research hot topic in the field of education and has been widely studied by scholars.

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Contribution of this paper to the literature

- This study proposes an improved problem-oriented teaching method to help students learn mathematics better.
- The improved problem-oriented teaching method provided in this paper contains detailed key steps. This method can deepen students' understanding of a concept and reduce the difficulty of solving mathematical problems. Thus, this method will assist in overcoming the difficulties in learning mathematics for students.
- This study highlights that the improved problem-oriented teaching method has shown a significant positive effect on enhancing students' mathematics achievement and reducing the differences in scores between urban and rural students compared with traditional teaching methods.

Table 1. 6-step problem-oriented teaching method

Step	Problem-solving teaching	Details
Step 1	Cognitive problem	What the question means? What are you looking for the answer? What are the concepts, theorems and formulas involved in this problem? Do you understand them?
Step 2	Analysis problems and solving it.	Have you ever had a similar problem? (1) If the answer is "Yes", what is that problem? What is the solution of that problem? Is it helpful to this problem? (2) If the answer is "No", what do you think of the present condition of the problem? What can you deduce or calculate? What is the ultimate solution to the problem? Then, you can ask your teachers and classmates to help you solve the problem.
Step 3	Summary results	After the solution of the problem, what kind of theoretical knowledge is used in this method? Including concepts, theorems, formulas, etc... Are you familiar with this knowledge? If you are not familiar with, review again.
Step 4	Method extensions	What other problems can be solved by this method? Can you solve a similar problem?
Step 5	Method comparisons	Is there any other way to solve this problem? What are the advantages and disadvantages of these methods?
Step 6	Sum-up and increasing	After solving this problem, what have you got? Including knowledge, methods and other aspects.

Examining the problem-solving process, Dufresne, Gerace and Leonard (1997) have proposed a model that can identify three key pieces of knowledge in the process. To enhance the students' problem-solving skills, Clough and Kauffman (1999) encouraged students to establish the repetitive connection between the theoretical concepts in various contexts and practical application. Flick (1993) noted that students' participation in practical activities can significantly improve their abilities in mathematics, logic, language, etc. Furthermore, it is more important that many studies have shown that a large proportion of students' understanding of mathematical concepts is significantly associated with mathematical problem-solving abilities (Dym, Agogino, Eris, Frey & Leifer, 2005; Gagne, Yekovich, & Yekovich, 1993; Luchins, 1942; Lutgens & Mulder, 2002).

The purpose of this paper is to consider the teaching of theoretical knowledge and deepen students' understanding of mathematical formulas through problem-solving. Thus, this study aims to develop a problem-oriented teaching method that allows students to overcome difficulties in learning mathematics (Brown & Walter, 2005). At the same time, we will use the results of the test performed in this study to evaluate the effectiveness of this teaching method.

Among the many theories of problem-solving strategies, the problem-solving method proposed by Polya in 1957 is more comprehensive than others. In his book "How to Solve It: A New Aspect of Mathematical Method", he suggested that the problem-solving process is divided into four steps that can improve student motivation and increase students' successful thinking habits: "(1) understands the problem, (2) devises a plan, (3) carries out the plan, and (4) reviews/extends" (Lee, 2017; Felmer et al., 2016; Polya, 1957).

However, in practical teaching, teachers have realized that how to design and implement an effective problem-solving plan is not easy for students. In fact, creating a new problem-solution plan is a rather difficult task. Therefore, we propose a new method oriented on the theory reported in the existing literature, which we named the "6-step problem-oriented teaching method", as shown in **Table 1**.

Students are asked to set up after-class discussion groups with each consisting of 2 or 3 members or to reflect on issues of concern on their own. We suggest that students should think about these issues one by one in the listed sequence. If some of them fail to consider all of the topics, they may only think about topics that they feel capable in. There is no fixed sequence of questions. The role of the teachers in these activities is to be promoters, who assist, remind and guide the learners in these critical thinking processes. The students are encouraged to seek help from multidimensional sources. They discuss the issues with teachers and fellow classmates and can surf the web or refer to books and periodicals that are available. The students in both classes share the same term exam paper assignment.

This new method adds more detailed key steps and can deepen the students' understanding of the concept while reducing their difficulty in solving mathematical problems.

The objective of this research is to develop a problem-oriented teaching method, which we have completed above. Then, the effectiveness of this method must be determined. In addition, previous studies have shown that there is a gap between urban and rural students in mathematics learning (Lee & McIntire, 2000; Young, 1998; Ye, 2016). As teachers in rural areas, we also consider the effective ways to bridge the gap. Therefore, we would like to check whether the problem can be effectively solved by a guided approach. We thus need to perform an empirical analysis to investigate the effectiveness of this method. To achieve this goal, we attempt to answer the following questions:

1. Is the problem-oriented teaching method more effective than the traditional teaching method for improving students' university mathematics achievement?
2. Is the problem-oriented teaching method more effective than the traditional teaching method in reducing the difference between urban and rural students' university mathematics achievement?

THEORETICAL FRAMEWORK

It is important for national development to find teaching methods that can maintain students' interest in learning mathematics and improve their problem-solving skills. To date, the teaching methods employed in teaching mathematics have not improved students' achievement and motivation in the subject to a considerable extent. As a result, developing a better mathematics teaching method has been and is becoming one of the core issues that scholars deal with in mathematics education.

Our approach aims at fostering students' positive attitudes towards mathematics and mathematics teaching and promoting a broader range of educational goals. The core objectives of the problem-oriented teaching method on university mathematics learning are to

- Increase students' interest in learning mathematics and to display the relevance of the steps in mathematical problem solving;
- Motivate students to develop their own interests in learning mathematics; and
- Promote students' competency in learning mathematics and their reflection upon when, why, and how the relevant mathematical knowledge points are used in mathematical problem solving

To achieve our research goals, we designed a teaching activity aimed at the students in a public university in China. Students should be at the central position in in-class teaching activities, and the teachers are supposed to encourage students to take initiative, ask questions, and analyse and solve problems. In the process of teaching, the teachers are secondary, playing the function of guiding and assisting students' learning. The students completed their learning of mathematics using the problem-oriented teaching method mentioned above, which consists of the following steps:

- In Step 1, the students should be acquainted with the details of the problem and understand what the problem considers. This means they should clarify the nature of the problem before proceeding to the next step.
- In Step 2, they are supposed to analyse the problem and find the way to solve it. They can solve the problems of the current situation by seeking the solution of similar problems, consulting teachers, and classmates to solve the problem. Ultimately, students need to design a solution to the problem.
- In Step 3, after executing their plan and solving this problem, the students must review the knowledge points involved in this problem, consolidating and summarizing the major points.
- In Step 4, students need to think about how to solve this problem and expand what problems can be solved.
- In Step 5, the students are required to reflect on whether there are any other ways to solve the problem, considering the advantages and disadvantages of different methods.
- In Step 6, the students are supposed to reflect on their achievements apart from the mere solution to the problem itself, including ideas, knowledge points, methods, etc., to further promote their knowledge and ability concerning problem-solving.

Polya indicates that there are two important objectives for teachers to help the student solve the problem and to develop the student's ability to solve the problem by himself or herself (Polya, 1957). We, therefore, developed an appropriate problem-oriented teaching method with six steps that can be applied to university mathematics learning.

Table 2. The number of participants by gender

Groups	No of students		Total	
	Male	Female	Subtotal	Overall total
Experiment	23	12	35	70
Comparison	17	18	35	

Table 3. The number of participants by region

Groups	No of students		Total	
	Urban	Rural	Subtotal	Overall total
Experimental	18	17	35	70
Comparison	14	21	35	

Table 4. The difference between the two groups students' scores on Pre-test

Group	Mean	SD	Differ	t	df	P
Experimental	53.5235	14.68499	5.71429	-1.001	34	0.120
Comparison	47.8092	13.38084				

STATEMENT OF VARIABLES

The research process of this paper included independent variables, dependent variables and control variables. The selection of variables and the structure of this study is as follows:

(1) Independent variable:

A. Experimental group: to provide data on the effects of the adaptive problem-oriented teaching method on students' mathematics learning.

B. Comparison group: to provide data on the effects of a traditional teaching method on students' mathematics learning.

(2) Dependent variable:

Learning effectiveness: compares the students' scores post-test and pre-test between the experimental and comparison groups.

(3) Control variable:

A. same teacher;

B. same number of students;

C. same syllabus and teaching content.

An adaptive problem-oriented teaching method was adopted for the experimental group, and a conventional teaching method was used for the comparison group.

We used the difference between the experimental and comparison groups pre-test and post-test to determine the learning effectiveness. A greater difference between the two groups indicates better learning effectiveness.

The teacher, syllabus, content, and teaching environment were the control variables in this study. Both the experimental and comparison groups were taught by the same teacher.

METHODOLOGY

Participants

To save human resources and time, we used a scientific random cluster sampling method to select a total of 70 students from two different classes to participate in the study. These 70 students were taking the Ordinary Differential Equation course offered by the Department of Mathematics at the University of Science and Technology Liaoning (USTL) during the autumn semester of 2016. Randomly chosen, one class was selected as the experimental group, and the other class was selected as the comparison group. The experimental group contained 35 students: 23 male students and 12 female students. The comparison group contained 17 male students and 18 female students. Demographic information of the participants in the study is shown in **Tables 2** and **3**.

Prior to the experiment, we used an independent t-test of their pre-test scores to examine the learning basis of the students in the two groups and determine whether there were significant differences between the two groups before taking part in the study. The results of the t-test are shown in **Table 4**, ($t= -1.001$ and $p=.120>.05$), which shows that there was no significant difference between the two groups in their initial scores.

Design and Procedure

To achieve the research objective and test the research hypotheses effectively, the experiment is divided into traditional teaching and problem-oriented teaching for 16 weeks with two hours of instruction per week (32 hours in total). The experimental and comparison groups were taking the same course with the same teacher, Professor Tu, who is also one of the authors of this paper. Professor Tu has no relatives, children or other stakeholders in these two classes; thus, the two classes are guaranteed the same fairness and justice throughout the semester. The only difference was that the experimental group used the problem-oriented teaching method, while the comparison group used the traditional teaching method.

With the traditional teaching method, the teacher's main task is to hand down their knowledge to the students through one-way in-class instructions. In this method, the teacher tells the students what he or she believes to be correct or important. The students' main task is to write down all the important information the teacher says and reinforce their knowledge and skills by later revision. With memorizing and rote learning as the students' major tasks, the students are discouraged to ask questions in class and are therefore unable to take interest in their learning.

Contrary to the abovementioned approach, the problem-oriented teaching method highlights the students' role of in-class dominance. The method's main goal is to help develop the students' spirit of exploration and self-learning ability with the teacher only assisting and helping. In in-class activities, the teacher inspires the students to find the problem and ask questions, supporting the students to find ways to solve the problem and acquire knowledge, providing them with necessary guidance and assistance upon requests. In this method, the students begin to take interest in learning knowledge, arousing their enthusiasm for exploration. Their previous passive learning is replaced by a new attitude of being active in acquiring and exploring knowledge, promoting their lifelong learning aptitude.

The above is an introduction to the instructional procedures of both the problem-oriented teaching method and the traditional teaching method; the following discusses the quantitative analysis of these methods. The basic data for the experimental and comparison groups, such as gender, urban and rural, were collected immediately prior to the teaching intervention, and the results are shown in **Tables 2** and **3**.

Before the start of the experiment, a pre-test was performed in the experimental and comparison groups to determine their basic level of knowledge.

In the first two weeks, the teacher explained the objectives of the study to all students and provided the syllabus of the proposed course, which listed all aspects of each class together.

Then, the students in the experimental and comparison groups were taught the same progression of curricula, following the same syllabus. However, as mentioned earlier, their teaching methods were different.

After the completion of the course that semester, the students in the experimental and comparison groups took part in the final test of the course, which was the same test in each group. The results of this post-test were used to evaluate the effectiveness of the problem-oriented teaching method versus traditional teaching method over time.

Typically, in Chinese culture, students are expected to listen to the tutor's instructions and accept them accordingly without any further questioning. Such a conventional way of treating the teacher's presentation results in large numbers of students who refuse to challenge and doubt academic explorations in a critical way. Not being encouraged to ask in-class questions, the students are less competent in exploring modern scientific knowledge. Therefore, in the in-class teaching practices, Professor Tu often encourages and guides the students to ask questions.

Data Analysis

We performed descriptive statistical analyses, such as the mean and standard deviation, and inferential statistical analysis, such as t-test, to determine the effect of the two different teaching methods (i.e., the problem-oriented and traditional teaching methods) on students' mathematics learning. In this study, all statistical analysis procedures and results were calculated using SPSS, and the statistical significance was set at 0.05 levels with two-tail tests.

RESULTS

According to the results of the mathematics achievement test, the purpose of this research is to prove each hypothesis stated in the following paragraphs.

Table 5. Comparison analysis of the two groups' students' scores on post-test and pre-test

Observations	Group	Paired differences					
		N	Mean difference	SD	t	df	P
Post-test and Pre-test	Experimental	35	18.70917	17.00133	6.510	34	0.000
	Comparison	35	10.13060	19.29692	3.106	34	0.004

Table 6. Comparative analysis of the two groups' students' scores in urban and rural areas

Group		Group	Mean	SD	Differ	t	df	P
Experimental	Pre-test	Urban	37.1389	12.20813	4.78595	1.361	33	0.183
		Rural	32.3529	8.03900				
	Post-test	Urban	53.3330	16.80341	-0.39212	-0.078	33	0.938
		Rural	53.7250	12.57650				
Comparison	Pre-test	Urban	39.7321	13.99844	3.42262	0.743	33	0.463
		Rural	36.3095	12.90274				
	Post-test	Urban	50.9520	15.15886	5.23805	1.140	33	0.263
		Rural	45.7140	11.97881				

Table 7. Adjusted and unadjusted means and variability using pre-test as a covariate

Groups	No	Unadjusted		Adjusted	
		M	SD	M	S.E
Experimental	35	53.5235	14.68499	53.5355	2.482
Comparison	35	47.8092	13.38084	47.8228	2.262

Comparison Analysis of both the Experimental and Comparison Groups

In the experimental group, the mean score of the students in the post-test (53.5235) was greater than that of the pre-test (34.8143). At the same time, for the comparison group, the mean score on the post-test (47.8092) was also greater than that of the pre-test (37.6786). A paired-sample t-test shows that the difference between the experimental group ($t_{(34)} = 6.510$, $p < 0.05$) and the comparison group ($t (34) = 3.106$, $p < 0.05$) was statistically significant. According to Cohen (1988), this difference is much larger than the general case. Although the students' scores for the two groups increased significantly, it is obvious that the increase in the experimental group was higher than that of the comparison group. The means, standard deviations, and t-values of the performance on the pre-test and post-test in the study are shown in **Table 5**.

Comparison Analysis of the Students' Scores in Urban and Rural Areas

T-test results showed no significant results when comparing the experimental and comparison groups, pre-test and post-test, and the difference between the average scores of urban and rural students. However, in the experimental group, the mean score of the urban students on the pre-test (37.1389) was greater than that of the rural students on the pre-test (32.3529); this difference was 4.78595. However, the mean score of the urban students on the post-test (53.3320) was lower than that of the rural students on the post-test (53.7250); the difference value was -0.39212. In contrast, for the comparison groups, the mean score of the urban students on the pre-test (39.7321) was greater than that of the rural students on the pre-test (36.3095); the difference was 3.42262. Unfortunately, the mean score of the urban students on the post-test (50.9520) was also greater than that of the rural students on the post-test (45.7140); the difference was 5.23805. The means, standard deviations, and t-values of the performance between the urban students' scores and the rural students' scores in the study are shown in **Table 6**.

Analysis of Covariance

The results of our observations implied that during the university mathematics learning process, the experimental group's mean score (53.5355) was higher than that of the comparison group (47.8228) after statistically controlling for the effect of the pre-test. **Table 7** shows the means and standard deviations for the experimental and comparison groups on the university mathematics learning test. As shown in this table, there is a reasonable difference between the experimental and comparison groups.

The analysis of covariance in **Table 8** indicates that a significant difference exists between the experimental and comparison groups in university mathematics learning ($F (l, 67) = 2.913$, $p=0.039< 0.05$, $\eta^2=0.042$). The effect size, eta-squared, is interpreted as small, medium and large effects if it equals 0.01, 0.06 and 0.14, respectively (Stevens, 1992). Because $\eta^2=0.042$ for this study, the effect size is close to medium.

Table 8. ANCOVA for the problem-oriented teaching method on university mathematics learning

Source	df	Mean square	F	P	η^2
Pre-test	1	11.686	.058	.810	.001
Group	1	582.852	2.913	.039	.042
Error	67	200.119			
Total	70				

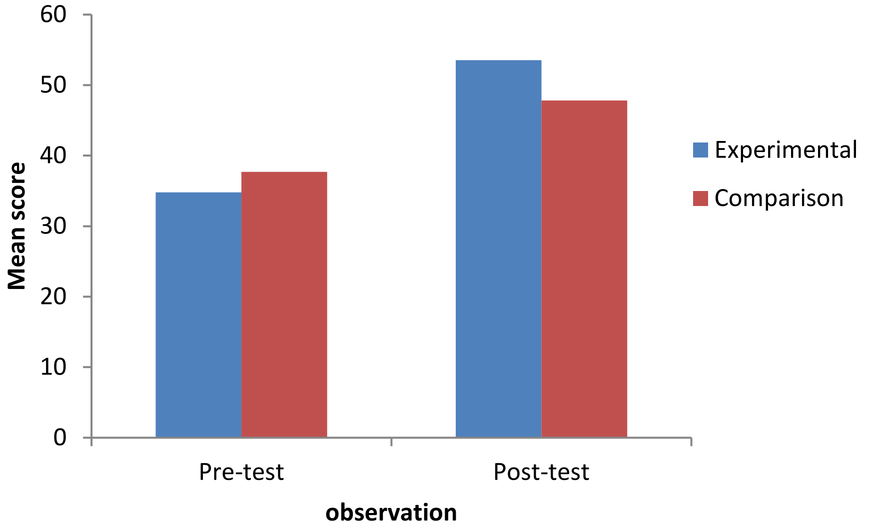

Figure 1. The effect of the problem-oriented teaching method on university mathematics learning

The mean scores of students in both experimental and comparison groups in pre-test and post-test are shown in **Figure 1**. As shown, the increased rate of the experimental group was higher than that of the comparison group; this increase was also significant with α = 0.05. The result of this study shows that the problem-oriented teaching method could be more effective in university mathematics learning than a traditional teaching method.

Interestingly, the students who asked questions frequently tended to have better academic achievements than those who were reluctant to ask questions. This phenomenon is more common in classes of the experimental groups. In this respect, it is helpful for mathematics teachers to assist their students by encouraging and guiding them to ask questions.

DISCUSSION AND CONCLUSION

This research proposed an improved problem-oriented teaching method that is used in a public university in China. After statistical analyses, including independent-samples t-test and paired-samples t-test, the results indicated that the mean scores of the experimental group's students that were taught with the problem-solving teaching method were found to be higher than that of the comparison group's students that were instructed with the traditional teaching method. In this regard, the problem-oriented teaching method is more effective in improving the students' mathematics achievement. Students actively participate in teaching activities in class, ask questions, answer questions, and discuss; these activities are beneficial to students' academic performance. The problem-oriented teaching method presented in this paper can promote discussion among students by asking and answering questions. Considering the abovementioned observations, scientific discussion is an important part of scientific exploration (Clark & Sampson, 2007). Therefore, the proposed teaching method is beneficial to the cultivation of students' consciousness of scientific exploration.

It is also universally acknowledged that students from urban and rural regions in China exhibit many differences in learning methods and habits. For example, they have different learning experiences, social backgrounds and economic support. Because of these differences, students from rural regions have an obvious disadvantage at the initial stage of university study. Consequently, it is important to explore whether we can effectively correct these differences by adjusting, improving and optimizing teaching methods. Therefore, we also analysed the impact of the new method on the differences between urban and rural students. We would like to know whether the new method has a different effect on urban and rural students and whether it can reduce the difference between urban and rural areas. In this regard, the empirical results show that, on average, there are some differences between urban and rural students. Traditional teaching methods cannot reduce this difference and can even increase the difference. However, using our new method of teaching, it is possible to gradually narrow the difference to achieve common student development and progress. Narrowing the gap between urban and rural areas is conducive to the friendly coexistence between students and the cultivation of the spirit of cooperation.

An additional but not redundant suggestion is that teachers should ask questions and guide students to ask questions. In the current study, if students were given sufficient time and encouragement, they had better outcomes. Students can ask questions and find the answers to the questions themselves. Therefore, teachers should encourage and promote students to actively ask questions, allowing students to think about these questions. The most important aspect of our new problem-oriented teaching method is that students can ask questions and try to answer these questions.

Future Research

For future research, some suggestions are as follows:

1. Qualitative research should also be considered. Through interviews with students, we could analyse the advantages and disadvantages of this method. This process may also facilitate the interviewed students' improvement in mathematics learning.
2. The problem-oriented teaching method proposed in this paper combined with other teaching methods, such as computer-assisted instruction, should be investigated regarding promoting students' mathematics learning speed and quality.
3. Other factors, such as gender and age, which are not considered in this study, should be examined in future studies.
4. It is clear that properly guided active learning methods are effective in helping improve learning. However, how this teaching method can be used in a systematic way and on a larger scale must be investigated further.
5. Qualitative studies and effect on gender is also an interesting area for further research.

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