Gender differences in mathematics academic performance of high school students in western China

Peijie Jiang
School of Mathematics and Statistics, Hunan Normal University, Changsha, China
Corresponding author’s e-mail: 52185500024@stu.ecnu.edu.cn

Abstract. The study describes gender differences in mathematics academic performance among high school students in western China. In this study, two research frameworks, knowledge structure and ability structure, were constructed to analyze the scores of western high school mathematics academic proficiency test, and the conclusion was drawn: female students’ mathematics academic performance in high school was significantly better than male students’; in sets, complex numbers, plane vectors, statistics, trigonometric functions, analytic geometry and functional knowledge modules, female students were significantly better than male students. There were no significant differences between male students and female students in common logic, inequalities, algorithms, probability, sequence, solid geometry and derivative knowledge modules. In terms of basic skills, mathematical operations and data analysis, female students were significantly better than male students. There were no significant differences between male students and female students in mathematical abstraction, logical reasoning and intuitive imagination. The design of mathematics curriculum and mathematics test should consider gender factors to ensure fairness.

1. Introduction
Mathematics is essential for students’ future career development [1]. For instance, mathematics is very important for most STEM jobs. In order to be competent for life and work in the future world, students must have a certain degree of mathematical literacy. Male students have a higher proportion of career choices in fields such as engineering and computing, which are highly related to mathematics [2]. There are many results in the study of gender differences in mathematics performance of male students and female students based on the data from international assessment projects such as The Program for International Student Assessment (PISA) [3]. Research results on PISA data show that male students’ performance in mathematics was significantly better than that of female students [4]. China’s PISA performance was excellent, but the cities that participated were the ones with the best economic and educational resources. China’s PISA performance cannot represent the average education level of China. In other words, the sampling method of PISA in China is not random, so its conclusions are not representative of the state of mathematics learning in western China. The judgement on the academic level of Chinese students in mathematics based on PISA data is incomplete. In addition, the participants of PISA were mostly junior high school graduates, so the gender differences in mathematics performance of high school graduates cannot be revealed.

In mathematical performance, male students and female students are different. In some areas, male students perform better in mathematics than female students. Female students are more likely to show anxiety and lack of confidence in mathematics than male students [5], and the fear of being inferior in mathematics is often unbearable [6]. Male students have the strongest belief in mathematics among
However, studies had also pointed out that the gender of female students has nothing to do with the average score in mathematics [8]. Female students perform better when the test content is consistent with the teaching content [9], while male students perform better when challenging items are involved in the test. So far, there are very few studies on Chinese students in this area. In some countries, the gender gap in mathematics achievement exists, but in others it does not. In China, the large-scale educational test that reveals the mathematics performance of high school students is the high school mathematics academic proficiency test. In order to more fully reveal the gender differences in mathematics performance of high school students, this research aims to answer the following two questions: 1) Are there gender differences in mathematics performance of high school students in western China? 2) What are the gender differences in mathematics knowledge and mathematical abilities of high school students in western China?

2. Research design
This section includes three parts, which are research materials, research tools and research methods.

2.1. Research materials
The research objects were the test questions of the general high school mathematics academic proficiency test in western China and the corresponding single-question score data. China’s high school mathematics academic proficiency test was a provincial-level national education test. It was organized and implemented by the provincial education administration. All students with ordinary high school status and completed high school mathematics courses must take the test. Passing the test was one of the prerequisites for graduation from high school, and it was also one of the important references for enrollment in higher education. The test comprehensively examined the mathematics abilities of senior high school students. There were 30 questions in the test paper, including 20 multiple-choice questions, 6 fill-in-the-blank questions, and 4 answer questions, with a maximum score of 100. The alpha reliability of the test questions was 0.91, the alpha reliability of the objective questions was 0.87, and the alpha reliability of the subjective questions was 0.80. The KMO value was 0.97. The content of the test question reflected the mathematics literacy required to complete high school mathematics in China. The measured difficulty of the whole volume was 0.69.

The sample data was a total of 2,800 students’ scores randomly selected from the score data. In the sample, 1,400 were selected from the data of male students and 1,400 were selected from the data of female students. The ratio of sample to population was approximately 1:100. The data of each candidate included the candidate’s gender and the score of each individual question. Due to research ethics considerations and the opinions of the data providers, this study could not provide more research-worthy data such as the names, identities, and family backgrounds of selected individuals, which are very important to explain the conclusion. Since the 29th and 30th questions each contained two small questions, the questions were respectively marked as 29(1), 29(2), 30(1) and 30(2).

2.2. Research tools
Mathematical performance is mainly reflected in mathematical knowledge and mathematical ability in this study.

In order to show the gender differences of senior high school mathematics in more detail, this study designed two statistical tools on knowledge modules and mathematical ability.

The knowledge modules included: sets, common logic, complex numbers, inequalities, plane vectors, algorithms, probability, statistics, sequence of numbers, trigonometric functions, solid geometry, analytic geometry, derivatives and functions.

This research divided mathematical ability into: basic skills, intuitive imagination, mathematical abstraction, mathematical operations, logical reasoning, and data analysis. The specific meaning of each mathematical ability was shown in Table 1. The specific meaning given in Table 1 was used as the basis when determining the mathematical ability tested in the questions.
| Mathematical Ability       | Meaning                                                                 |
|----------------------------|-------------------------------------------------------------------------|
| Basic Skills               | • understand the concepts, properties, relationships, laws, formulas and theorems involved in the required courses in the curriculum standards  
                          | • be able to perform simple mathematical operations, data processing and chart drawing according to certain procedures |
| Intuitive Imagination     | • be able to establish the connection between simple figures and objects in familiar situations, and be able to describe the positional relationship and measurement relationship of simple spatial forms and their unique properties |
|                           | • be able to intuitively understand mathematical problems through graphics, and be able to use graphics to express familiar problems to inspire ideas for solving these problems |
| Mathematical Abstraction  | • understand the meaning of mathematical concepts and rules, understand the conditions and conclusions of propositions, and be able to abstract mathematical problems in familiar situations |
|                           | • be able to directly abstract mathematical concepts and rules in familiar situations, understand reasoning and argument expressed in mathematical language, and be able to explain related abstract concepts in combination with actual situations |
| Mathematical Operations   | • be able to understand the object of operation in a familiar mathematical context, raise operational problems, and establish appropriate operational ideas to solve problems according to the characteristics of the problem |
|                           | • understand the algorithm and its scope of application, be able to perform operations correctly, use operations to verify simple mathematical conclusions, and use the results of operations to illustrate problems |
|                           | • be able to discover quantity or graphic nature, quantity relationship or graphic relationship by induction or analogy in familiar situations |
| Logical Reasoning         | • understand the logical relationship between conditions and conclusions of familiar mathematical propositions, and be able to prove simple mathematical propositions methodically |
|                           | • be able to understand random phenomena in familiar situations, and be able to choose appropriate probability models to solve familiar probability problems |
| Data Analysis             | • be able to select appropriate sampling methods to collect data for familiar statistical problems, and use basic statistical methods to describe, characterize and analyze data to solve problems |
The researcher first judged independently and then discussed with experts to determine the knowledge modules examined in each question. The results were shown in Table 2. Question 28 examines both statistics and probability, and was included both in the statistics and probability modules.

**Table 2. Knowledge module and corresponding question number.**

| Module                  | Number       |
|-------------------------|--------------|
| Set                     | 1            |
| Common Logic            | 14, 21       |
| Complex Numbers         | 4            |
| Inequality              | 9, 22        |
| Plane Vector            | 7            |
| Algorithm               | 8            |
| Probability             | 24, 28       |
| Statistics              | 11, 28       |
| Sequence                | 23, 27       |
| Trigonometric Function  | 2, 16, 17, 20|
| Solid Geometry          | 3, 29        |
| Analytic Geometry       | 6, 12, 13, 19, 26|
| Derivative              | 30           |
| Function                | 5, 10, 15, 18, 25|

For example, the 23rd question was: “What is the common ratio q of the geometric sequence 1, 2, 4, 8, ...” This question examines the knowledge module sequence.

The ability to answer the test questions was shown in Table 3. Among them, questions 28 and 29 (2) tested two kinds of mathematical abilities at the same time.

**Table 3. Mathematical ability and corresponding question number.**

| Mathematical Ability     | Number                                                  |
|--------------------------|---------------------------------------------------------|
| Basic Skills             | 1, 2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26 |
| Intuitive Imagination    | 27                                                      |
| Mathematical Abstraction | 14, 21, 29(1), 30(2)                                   |
| Mathematical Operations  | 3, 18, 29(2)                                           |
| Logical Reasoning        | 28, 29(2), 30(1)                                       |
| Data Analysis            | 28                                                      |

For example, Question 25 was: “What is the maximum value of the function \( f(x) = x^2 - 2x - 1 \) in the interval \([0,3]\).” The requirement of this question was “be able to perform simple mathematical operations in accordance with a certain procedure”. Therefore, the mathematics ability tested was the basic skill.

2.3. Research methods
SPSS 22 was used to process the performance data, and the independence test was performed on the related performance of male students and female students (independent t-test). The specific content of the study was as follows.
To describe and test the difference between the scores (the total score, the scores of each knowledge module and the scores of each mathematical ability) of male students and female students.

3. Research result
This section presents the results of the research, which is divided into three parts.

3.1. Comparison of the total test scores between male students and female students
The descriptive statistics of the total scores of male students and female students are shown in Table 4.

| Total score | N  | Minimum | Maximum | Mean     | Std. Deviation |
|-------------|----|---------|---------|----------|---------------|
| Male        | 1400 | 9.00   | 100.00 | 67.5379 | 21.37674 |
| Female      | 1400 | 14.00  | 100.00 | 69.9829 | 18.74591 |

Table 4 shows that the average score of male students in the sample (67.5379) is lower than that of female students (69.829), and the average score difference is 2.4450. The standard deviation of male students’ scores (21.37674) is higher than the female students’ scores (18.275). The degree of dispersion of male students’ grades is greater.

The test results in Table 5 show that the $F$ value is 44.695, and the significance value is less than 0.05, so the hypothesis of homogeneity of variance is rejected at the 0.05 significance level. The variances are not equal. The value of $t$ is -3.218, and $p = 0.001 < 0.05$. There is a significant difference in the total score of male students and female students at the 0.05 level of significance. The total score of female students is significantly higher than that of male students. However, the effect size of the difference was small ($r = 0.06 < 0.1$).

| Levene's Test for Equality of Variances | t-test for Equality of Means |
|----------------------------------------|-----------------------------|
| $F$                                     | $p$                         |
| Equal variances assumed                 | $-3.218$                    |
| Equal variances not assumed             | $2798$                      |
| $df$                                    | $0.001$                     |
| $p$                                     | $-2.4450$                   |
| Std. Error Difference                   | $0.7599$                    |

3.2. Comparison of the scores of mathematics knowledge modules between male students and female students
The descriptive statistical results of the average scores of male students and female students in each knowledge module and independent sample t-test results are shown in Table 6.

It can be seen from Table 6 that the average score of male students in the sequence module (6.07) is slightly higher than that of female students (6.06), while the average score of male students in other modules is lower than that of female students. In sets ($t = -4.553, p < 0.001, r = 0.09$), complex numbers ($t = -3.741, p < 0.001, r = 0.07$), plane vectors ($t = -2.902, p < 0.01, r = 0.05$), statistics ($t = -3.557, p < 0.001, r = 0.06$), trigonometric functions ($t = -2.100, p < 0.05, r = 0.04$), analytic geometry ($t = -5.196, p < 0.001, r = 0.10$) and functional knowledge modules ($t = -4.567, p < 0.001, r = 0.09$), male students score significantly lower than that of female students. The standard deviation of the scores of all knowledge modules for male students is greater than that for female students. The discreteness of the scores of male students in each knowledge module is higher than that of female students.
Table 6. T test for the mean scores of each knowledge module.

| Module                | Mean (M) | Mean (F) | S.D. (M) | S.D. (F) | t    | p     | Sig. (2-tailed) |
|-----------------------|----------|----------|----------|----------|------|-------|-----------------|
| Set                   | 2.63     | 2.79     | 0.98     | 0.77     | -4.553 | 0.000 | ***             |
| Common logic          | 3.97     | 3.99     | 1.50     | 1.47     | -0.471 | 0.638 |                |
| Complex numbers       | 2.63     | 2.76     | 0.99     | 0.82     | -3.741 | 0.000 | ***             |
| Inequality            | 3.85     | 3.87     | 1.61     | 1.56     | -0.393 | 0.694 |                |
| Plane vector          | 2.76     | 2.84     | 0.81     | 0.67     | -2.902 | 0.004 | **              |
| Algorithm             | 2.89     | 2.91     | 0.56     | 0.50     | -1.071 | 0.284 |                |
| Probability           | 4.04     | 4.25     | 3.19     | 3.14     | -1.741 | 0.082 |                |
| Statistics            | 5.59     | 5.99     | 3.04     | 2.95     | -3.557 | 0.000 | ***             |
| Sequence              | 6.07     | 6.06     | 2.59     | 2.48     | 0.172  | 0.864 |                |
| Trigonometric function| 8.77     | 9.05     | 3.62     | 3.40     | -2.100 | 0.036 | *              |
| Solid geometry        | 6.04     | 6.05     | 3.09     | 2.73     | -0.078 | 0.938 |                |
| Analytic geometry     | 9.26     | 10.09    | 4.40     | 3.97     | -5.196 | 0.000 | ***             |
| Derivative            | 0.95     | 0.99     | 1.70     | 1.67     | -0.628 | 0.530 |                |
| Function              | 11.10    | 11.70    | 3.78     | 3.20     | -4.567 | 0.000 | ***             |

Note: * p < 0.05, ** p < 0.01, *** p < 0.001

3.3. Comparison of the scores of mathematics abilities between male students and female students

The description and independent test results of the scores of each mathematics ability of male students and female students are shown in Table 7.

Table 7. The t test of the scores of mathematics ability.

| Mathematical ability  | Mean (M) | Mean (F) | S.D. (M) | S.D. (F) | t    | p     | Sig. (2-tailed) |
|-----------------------|----------|----------|----------|----------|------|-------|-----------------|
| Basic skills          | 46.96    | 49.03    | 13.79    | 11.66    | -4.298 | 0.000 | ***             |
| Intuitive imagination | 4.47     | 4.38     | 2.22     | 2.18     | 1.110  | 0.267 |                |
| Mathematical abstraction| 6.10   | 6.17     | 2.91     | 2.72     | -0.658 | 0.511 |                |
| Mathematical operations| 4.96    | 5.28     | 4.40     | 4.16     | -1.977 | 0.048 | *              |
| Logical reasoning     | 6.30     | 6.30     | 2.57     | 2.29     | -0.062 | 0.950 |                |
| Data analysis         | 3.01     | 3.35     | 2.58     | 2.55     | -3.492 | 0.000 | ***             |

Note: * p < 0.05, ** p < 0.01, *** p < 0.001

In mathematics abstraction (4.47), male students’ score slightly higher than the female students’ (4.38). In other mathematical abilities, male students’ score no higher than the female students. In basic skills \((t = -4.298, p < 0.001, r = 0.08)\), mathematical operations \((t = -1.977, p < 0.05, r = 0.04)\) and data analysis \((t = -3.492, p < 0.001, r = 0.07)\), male students’ scores significantly lower than that of the female students. There is no significant difference between male students and female students in the scores of mathematical abstraction, logical reasoning and intuitive imagination.

4. Conclusion

There are gender differences in mathematics performance of high school students in western China. Female students’ high school mathematics academic performance is significantly better than that of male students, and male students’ scores have greater variability. In the knowledge modules of sets, complex numbers, plane vectors, statistics, trigonometry, analytic geometry and functions, female students were significantly better than male students. There were no significant differences between male students and female students in common logic, inequalities, algorithms, probability, sequence of numbers, solid geometry and derivative knowledge modules. In basic skills, mathematical operations
and data analysis abilities, male students are significantly lower than female students. There is no significant difference between male students and female students in mathematical abstraction, logical reasoning and intuitive imagination.

The conclusions of this study are inconsistent with the conclusions of the research results based on PISA. That’s because the samples selected in this study are limited to western China, and the high school mathematics academic proficiency test in this article mainly examines the regular teaching content of ordinary high schools, which is not challenging. In the math test of challenging items, male students often get better results, which can be seen from the fact that most of the international mathematics Olympians are male students. This research helps to correctly understand the gender characteristics of male students and female students in mathematics learning. The view that male students are generally better at mathematics is questionable. As far as high school in western China is concerned, female students’ mathematical performance may be better than that of male students. Presenting this point of view to the public will help female students overcome their fear of studying mathematics and will ultimately help them learn mathematics more confidently. There should be no gender discrimination in mathematics learning, and the design of mathematics courses and math exams should consider gender factors to ensure fairness. Mathematics teachers should give students the correct hint that female students’ mathematics scores will not be bad because of their gender. For anyone, whether male or female, the main reason for poor math grades is not studying hard.

Due to the requirements of confidentiality and research ethics, the research did not reveal factors such as individual family status, family education resources and age, which are all important to explain the conclusion. In addition, the effect sizes of differences in this study were all very small. Although the t-test results are significant, it is possible that such significance is due to a large sample (N = 1400 for each gender group). Therefore, although the sample was randomly selected, the application value of the conclusion is limited.

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