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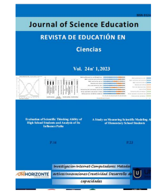

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Evaluation of Scientific Thinking Ability of High School Students and Analysis of Its Influence Paths

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A R T I C L E I N F O

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Evaluation

A B S T R A C T

At the 20th National Congress of the Communist Party of China, the important task of "comprehensively improving the quality of independent talent cultivation and focusing on cultivating top-notch innovative talents" was clearly proposed. Scientific thinking, as one of the four core competencies in physics, is of great significance for cultivating students' creativity.This research team developed scientific thinking assessment questions and distributed questionnaires to several high schools in Jiangsu Province to conduct in-depth analysis of the current situation and impact paths of scientific thinking among high school students.Research has found that high school students' scientific thinking ability is currently at a relatively low level, with most students showing a correlation between their physics grades and scientific thinking level. However, there is still a portion of students who have not reached a balance between the two. Among them, scientific subject identification has a direct and significant impact on students' scientific thinking level.It is recommended to implement teaching methods from the perspectives of physics concepts, laws, experiments, and exercises to further achieve thinking development, pay attention to the impact of scientific subject identification on scientific thinking ability, pay attention to factors such as teacher-student relationship, teacher teaching, and scientific learning attitude, and pay attention to individual differences between students, in order to achieve a balanced development of physics grades and scientific thinking.

1. Research background

The term "core literacy" is increasingly valued by educators, and organizations or countries such as the Organization for Economic Cooperation and Development, the European Commission, and the United States have all established a "core literacy framework".Chinese educators have also proposed the "Core Literacy Framework for the Development of Chinese Students", in order to better achieve the fundamental task of "cultivating morality and cultivating talents".Core literacy is an important concept in China's current curriculum reform, which is the goal of the curriculum and also a concentrated reflection of the educational value of the subject，（The PRC Ministry of Education，2022）In the "Physics Curriculum Standards for Ordinary High Schools" (revised in 2017 and 2020), it is explicitly stated that "scientific thinking" is one of the four core competencies of physics, and it is pointed out that developing students' scientific thinking ability is an important teaching goal in middle school physics teaching. Therefore, the cultivation of scientific thinking plays an important role in physics education. Middle school students have a certain level of analytical and comprehensive scientific thinking process in their studies, which helps to enhance their comprehensive abilities and provides a foundation for cultivating students' innovative abilities. At present, cultivating top-notch innovative talents is the main task of education in various countries around the world. At the 20th National Congress of the Communist Party of China, it was clearly stated that the important task of "comprehensively improving the quality of independent talent cultivation and focusing on cultivating top-notch innovative talents" is to be achieved. The cultivation of top-notch innovative talents requires consideration of factors such as background, family, community, and school, all of which have a significant impact on the development of individual creativity and abilities. Researchers propose that everyone has the potential for innovation and creation, and top-notch innovative talents grow up.

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Education should cultivate everyone's creativity, so it is imperative for teachers to develop students' scientific thinking abilities in teaching. The main forms of scientific thinking assessment in China are mainly focused on interviews, classroom responses, exams, etc., but there is a lack of development of evaluation standards.

2. Research method

2.1 Participants and evaluation tools

In order to test the effectiveness of the proposed evaluation tool, this study used the high school department of a demonstration high school in Jiangsu Province as an experimental school, and randomly selected 467 students from the school's third year of high school as test subjects. A total of 467 test papers were collected, and 88 invalid test papers (unanswered or extensively blank) were excluded. A total of 379 valid questionnaires were collected, with a validity rate of 81.16%. The high school has a rich source of students, excellent teaching quality, and certain differences among student groups. During the evaluation research, the students who have completed all the physics knowledge involved in the test questions can be used as the research object of this test.

This study obtained data through standardized physics exams, scientific thinking test papers, and questionnaire surveys. Standardized physics exams are used to collect students' physics scores.

The test paper is compiled by subject experts invited by the higher education regulatory department and provides unified reference answers, thus having good expert reliability.The test paper is based on a percentage system and is collectively reviewed and verified by two physics teachers, with good consistency. The scientific thinking test paper is used to collect students' scientific thinking level. The process of preparing test papers is as follows: (1) Selected questions for examining scientific thinking from the 2019 to 2022 high school physics test papers collected from the official websites of the four major examination centers in the UK and education websites in 50 states in the United States; (2) Classify and summarize the questions according to the knowledge points examined, and select high-frequency test points; (3) Compare the high-frequency test points with the high school physics curriculum standards, select knowledge points that overlap with the test questions, and after four rounds of discussion by the physics education expert group and frontline teachers, select the examination topic as "force and motion"; (4) Three situational based scientific thinking ability test questions were selected under the knowledge points of "force and motion" for adaptation, forming a scientific thinking test paper that examines nine dimensions: raising questions and making assumptions, designing experiments and generating data, interpreting data and drawing conclusions, viewpoints, facts and theoretical basis, reasoning and refutation, model construction and use, model testing and correction, modeling metacognition and metamodeling knowledge. Each dimension has 3 questions, totaling 27 items. Finally, the scientific and normative nature of the questionnaire was ensured through four rounds of discussions between the physics education expert group and frontline teachers.

The background questionnaire mainly includes basic information, socio-economic level, scientific learning attitude, scientific subject identification, teacher-student relationship, teacher teaching, and learning behavior. To ensure the stability and effectiveness of the scale questions in this questionnaire, SPSS 25.0 software was used to test the reliability of all questions in the questionnaire, and the overall clonal Barthes α The value is 0.931, with good reliability. The common factors extracted from exploratory factor analysis can cumulatively explain 52.102% of the variance, and the factor loadings are all greater than 0.6. The questionnaire has good structural validity.

2.2 Quality of scientific thinking assessment tools

In order to verify the quality of the evaluation tools, this study was based on the Rasch model and analyzed using Winstep software. The results are shown in Table 2. In terms of reliability, we measured the main reliability indicators in the Rasch model, including subject reliability (0.88) and question reliability (0.99). At the same time, this study conducted reliability analysis on the test questions using SPSS, Cronbach's α The coefficient is 0.923, and the above reliability indicators indicate that the results of this measurement have high stability. In order to verify whether the measurement scale and project structure can effectively distinguish the scientific thinking level of the subjects, this study conducted a separation test, with a separation degree of 2.75 for the subjects and 8.75 for the test questions. This indicates that the scientific thinking level of the subjects and the difficulty of the test questions have a good differentiation in structure. In terms of validity, the evaluation indicators of the Rasch model mainly include single dimensionality of test questions, fit of test questions, and grading structure of test questions. The unidimensionality of the test questions reflects whether each item in the testing tool can assess the same level of ability of the subjects. Most dimensions in this testing tool fall between -0.4 and 0.4, indicating that the testing tool only measures one potential trait and has unidimensionality.In terms of test item fit, the values of ZSTD for each item in the Fit and Outfit fit indices range from -2.0 to 2.0, the values of MNSQ range from 0.70 to 1.30, and the values of point measurement correlation (PT-MEASURE CORR.) are all between 0 and 1, indicating a good fit between the measured data of the test item and the model. In terms of the scoring structure of the test questions, the scoring level category curve of each dimension has a clear peak and is flat, and covers a certain range in the horizontal axis, performing well. This indicates that the evaluation tool designed in this study can effectively evaluate the scientific thinking ability of the subjects.

Table 1 Reliability and Validity Test Results of the Scientific Thinking Test Tool

index	Evaluation results
reliability	Subject reliability：0.88 Test question reliability：0.99 Cronbach's α: 0.923
Resolution	Test separation degree：2.75 Test question separation：8.75
Single dimensional test questions	Most of the questions fall between -0.4 and 0.4, which meets the requirement of unidimensionality.
Fit of test questions	The measured data of the test questions fit well with the model
Grading structure of test questions	fine

2.3 Characteristics of students' scientific thinking

The Wright chart (Figure 1) provides information on the matching of project difficulty distribution with the level of participants' abilities. The Wright chart lists the locations of 379 students and 27 projects in a universal scale.The second column is the logit scale, while the first and third columns graphically depict the positions of the participants and 27 items, respectively. The Wright chart converts student scores and project scores in logit units using a universal interval scale. For this study, students and projects paired the quantity table from -4 to+2 logits. From top to bottom, students' abilities and difficulty of the test questions decrease in order.Each '#' represents 2 students, and each '.' represents 1 student. The adequacy and effectiveness of the test questions can be evaluated based on the distribution and ranking of items in the White chart. The difficulty distribution range of the test questions is about 4 logits, with the most difficult being 1.86 logits for project JMZSA and -1.88 logits for project TLJSA. Visual inspection shows that there is no significant gap between the items, indicating that the difficulty distribution of the test questions is good, and the content is sufficient and effective. In terms of level matching, the distribution range of subjects' scientific ability level and difficulty of the test questions is wide, with significant differences, showing a normal distribution feature of less at both ends and more in the middle. The default average difficulty of the test question is 0.00logit, while the average ability of the subject is -1.03logit, indicating that the range of the subject's ability level is smaller than the difficulty distribution of the test question. The maximum ability value of the subjects is 1.69 logit, the minimum is -3.89 logit, and the mode of the ability value is -0.29 logit. There are a total of 20 people, indicating that the subjects' scientific thinking ability is at a lower than average level.

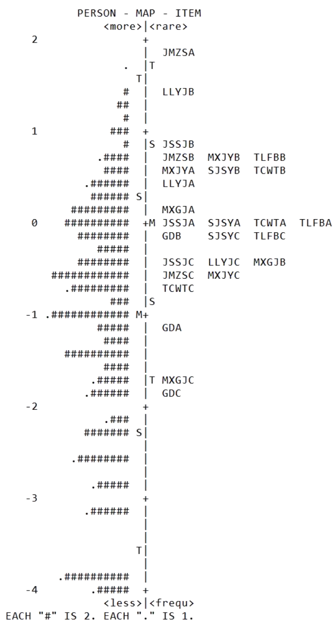

Figure 1 Wright diagram

3. Performance level of students' scientific thinking ability

3.1 The overall and multi-dimensional expression of scientific thinking ability

There are three primary indicators for scientific thinking, namely scientific reasoning, scientific argumentation, and scientific modeling. Under each primary indicator, there are 3 secondary indicators, totaling 9. Scientific reasoning includes raising questions and making assumptions, designing experiments and generating data, interpreting data, and drawing conclusions;Scientific argumentation includes viewpoints, facts and theoretical basis, reasoning and refutation; Scientific modeling includes model construction and use, model verification and correction, modeling metacognition, and metamodeling knowledge. The full score for each dimension of scientific thinking is 2 points, and the overall average score for scientific thinking is 0.62 points. Among them, the score for scientific reasoning is 0.57 points, the score for scientific reasoning is 0.67 points, and the score for scientific modeling is 0.62 points. The score for scientific reasoning is the highest, while the score for scientific reasoning is the lowest (Figure 2).

To further characterize the specific performance of subjects' scientific thinking ability, descriptive statistics and scoring rate calculations were conducted on 9 dimensions of scientific thinking ability in this study.From descriptive statistics of various dimensions of scientific thinking ability, it can be seen that students have the highest average score (1.02) in the "viewpoint" dimension, with a score rate of 0.51, followed by "model construction and use" (average score=0.88, score rate=0.44) and "posing questions and making hypotheses" (average score=0.62, score rate=0.31); The scoring rates of other dimensions are all below 0.3, which is at a relatively low level; The lowest score in the dimension of "modeling metacognition and metamodeling knowledge" (0.46 points), with a score rate of only 0.23.

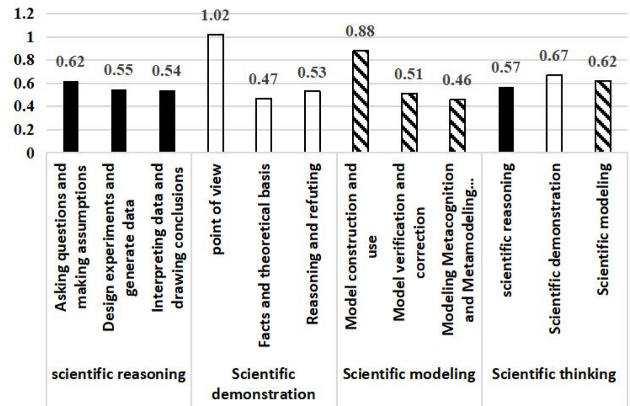

Figure 2 Mean distribution of students' scientific thinking performance

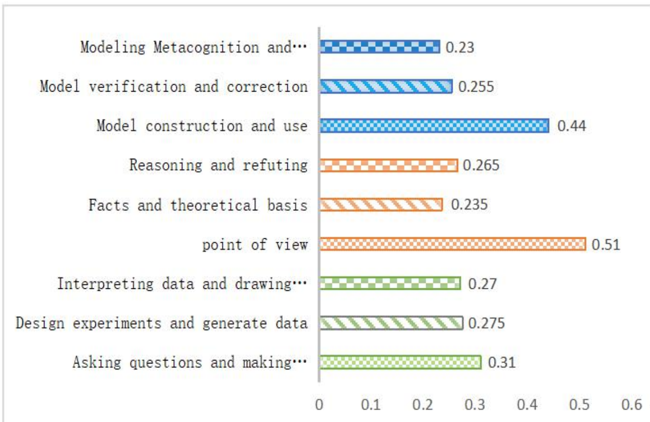

Figure 3 Scoring rate of test items

3.2 The horizontal distribution of scientific thinking ability

According to the difficulty of the test questions, students' ability levels are divided into three levels, namely Level 0, Level 1, and Level 2. The abilities increase in order. It can be observed on the percentage distribution map of scientific thinking performance level of high school students in Jiangsu Province that Level 0 accounts for the most and Level 2 accounts for the least in the quantity distribution of the three levels. Most students' scientific thinking abilities are at levels 0 and 1, while only a small number of students reach level 2.From the perspective of nine dimensions, the dimensions of "modeling metacognition and metamodeling knowledge", "reasoning and refutation", "facts and theoretical basis", "interpreting data and drawing conclusions", and "designing experiments and generating evidence" exhibit similar patterns, that is, the proportion of students gradually decreases from level 2 to level 0, and the proportion of students at level 0 is around 60%, level 1 is about 25%, and level 2 is about 15%;The highest proportion of level 0 in the dimensions of "model correction and testing" and "raising questions and making assumptions" is around 60%, followed by level 2, which accounts for about 20%, and level 1, which accounts for the lowest proportion of about 15%; Level 2 of the "Model Construction and Use" dimension accounts for 44.4%, Level 1 accounts for 23.4%, and Level 0 accounts for 32.2%; The "viewpoint" dimension has an average of three levels, all around 30%.

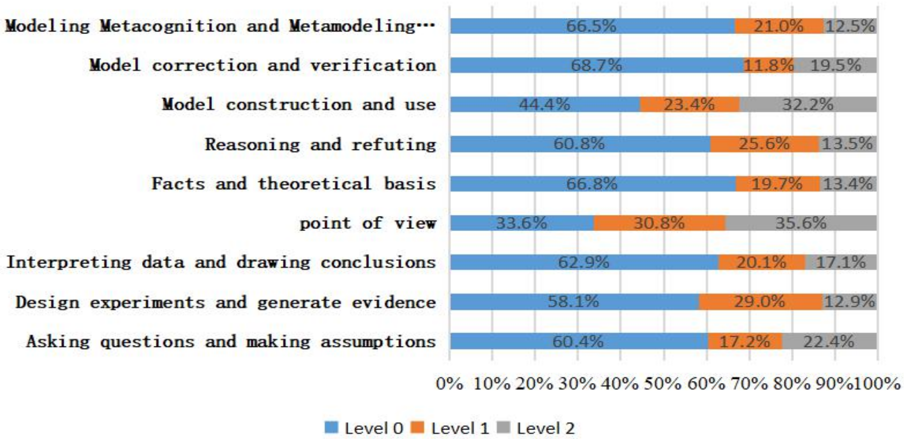

Figure 4 Percentage distribution of students' scientific thinking performance level

4. Path Analysis of Factors Influencing Students' Scientific Thinking Ability

4.1 The Theoretical Basis of Path Drawing

(Chen Yiru,2022)Researchers have found that in addition to their own factors, the social environment in which teenagers are located also affects their ability to use scientific methods to ask and solve problems.To explore which factors significantly affect scientific thinking, this study conducted a questionnaire survey on students' scientific subject identification, learning behavior, scientific learning attitude, as well as background factors such as teachers' teaching methods and teacher-student relationships. Based on previous research findings, hypotheses were proposed and a model was established based on this data.

（Engel， 1995） Attitude theory states that beliefs and feelings constitute attitudes, which in turn directly affect the formation of behavioral intentions and, on this basis, influence human behavior. Based on this, this study proposes the hypothesis that ① scientific learning attitudes affect students' learning behavior.

（Brekelmans, Wubbies, Brok， 2002） Luda analyzes the impact of teacher-student relationship on learning behavior from the emotional perspective based on the extended dependency perspective and the theory of self systems. The extended dependency perspective believes that good teacher-student relationship and teacher support factors are the key factors for students to develop learning behavior.（Deng Xiao， 2002） In addition, the researchers' analysis of the influencing factors of teacher-student relationship also emphasizes students' academic achievements, personality characteristics, psychological state and teachers' teaching. Based on the above theoretical foundations, this study proposes hypotheses: ② teacher-student relationship affects students' learning behavior, ③ teacher-student relationship affects students' scientific learning attitude, ④ teacher-student relationship affects students' scientific subject identification, and ⑤ teacher-student relationship affects teachers' teaching.

There are certain differences in the learning behavior of students with different grades, and often students with good behavior habits have excellent grades. Therefore, students' learning behavior habits are closely related to their academic performance,（Lu Shuang, 2014）The cultivation of good learning behavior plays a crucial role in achieving good academic performance. Based on this, hypothesis of this study is proposed that ⑥ students' learning behavior affects their physics grades.

Discipline identity can also be called professional satisfaction, which is an indicator reflecting students' positive psychological state and can create a positive emotion. （Reschly, Huebner, Appleton& Antaramian,2008） It enhances individuals' sense of control and stability in learning and life, while providing students with a higher sense of self-worth.Students with high identification are often more able to follow the teacher's instructions, comply with school regulations, and actively engage in learning; （Prince Yan， 2020） However, students with low identification tend to have more avoidance tendencies due to negative emotions towards the subject they are studying, and are unable to efficiently engage in learning tasks. （Nauta，2007） Some scholars have found a mutually reinforcing relationship between professional satisfaction and the performance of each student. Therefore, hypothesis is proposed that ⑦ scientific discipline identity affects students' physics grades.

This study refers to students' self-efficacy and self-monitoring level as scientific learning attitudes. (Bandura ,1977)Bandura found in his research that "academic self-efficacy can significantly positively predict academic achievement. (Zhang Xuemin, Lin Chongde, Shen Jiliang, Guo Dejun,2007) Other scholars have also found that students' self-efficacy not only affects their academic performance, but also their self-efficacy. The two factors interact and are mutually causal. In summary, there is a significant correlation between academic self-efficacy and academic performance, and the level of students' academic self-efficacy will affect their performance in the learning process.(Zhang Feng, Liu Cong,2012) The relationship between self-monitoring and grades is equally close, showing a significant positive correlation. Students with higher grades have significantly higher levels of self-monitoring than those with lower grades. Based on the above theoretical foundation, this study proposes hypothes is that ⑧ scientific learning attitude affects students' physics grades.

The relationship between scientific thinking and academic performance has always been an important research direction in the field of education research.(Dong Siyan,2022)Some studies have shown that cultivating scientific thinking ability can help improve students' academic performance, especially in science and mathematics. Some empirical studies have also pointed out a significant positive correlation between scientific thinking and academic performance.Therefore, this study proposes the hypothesis that there is a mutual influence between scientific thinking and physical performance. If Hypothesis ⑨ holds the covariant relationship between scientific thinking and physics grades, combined with Hypothesis ⑥-⑧, Hypothesis ⑩-⑫is proposed, which states that students' learning behavior, scientific subject identification, and scientific subject attitude affect their scientific thinking, in order to further explore the background factors that affect scientific thinking

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4.2 Correlation analysis of research variables

A correlation analysis was conducted on 8 variables, including scientific thinking, physics scores, scientific subject identification, teacher-student relationship, teacher teaching, learning behavior, and scientific learning attitude. The results are shown in Table 4, indicating a positive correlation between the variables and meeting the criteria for constructing a structural equation model.

Table 2 Data Statistics and Correlation Analysis of Research Variables

	Scientific thinking	Achievement	Scientific discipline identification	teacher-student relationship	Teacher teaching	Learning behavior	Scientific learning attitude
Scientific thinking	1						
Achievement	.272**	1					
Scientific discipline identification	.180**	.206**	1				
teacher-student relationship	.211**	0.061	0.075	1			
Teacher teaching	.139**	0.096	0.078	.375**	1		
Learning behavior	.155**	.181**	.106*	.327**	.397**	1	
Scientific learning attitude	.182**	.202**	.113*	.428**	.391**	.592**	1

Note: N=377； ** Indicating p<0.01, * indicating p<0.5, with significant correlation

4.3 Path inspection results

This study used Harman's single factor test method to conduct exploratory factor analysis on all items. The results showed that three factors had characteristic root values greater than 1, and the first factor explained a total variance value of 32.440%, which was below the 40% critical value standard. This indicates that there is no serious common method bias in this study.

This study used AMOS 24.0 for structural equation model construction. Firstly, the index test of model fit was conducted. The chi square degree of freedom ratio of the model was 2.179<3, RMSEA=0.056<0.08, PNFI=0.228<0.5, GFI=0.990>0.9, AGFI=0.948>0.9, and the data showed good fit to the model.

In the model validation stage, this study first examined the covariation relationship between scientific thinking and physical performance（ β= 35.960, t=4.254**), the test results showed significance, therefore hypothesis ⑨ was verified. In addition, the model results show that teacher teaching and teacher-student relationships（β=. 375, t=6.778***), Scientific Learning Attitude and Learning Behavior（β=. 447, t=8.281**) There is also a significant covariant relationship between the two, which means that there is also mutual influence between teacher teaching and teacher-student relationship, as well as between scientific learning attitude and learning behavior. Hypotheses ① and ⑤ have been verified, and based on these two hypotheses, learning behavior can in turn affect scientific learning attitude, and teacher teaching can also affect teacher-student relationship.

Except for covariant relationships, the other path assumptions are shown in Table 5. Bold font represents a path with significant effects, while light font represents a path with significant effects. A total of 7 hypotheses were accepted, and in order to more clearly indicate the relationship between variables, this study plotted the significant paths in Figure 3. Firstly, verify the direct impact of each variable on physical performance and scientific thinking. From the test results, it can be seen that scientific discipline identification（β= 3.032, t=3.564***) and scientific learning attitude（β= 1.915, t=2.096*) has a significant positive direct effect on physical performance, and in terms of its impact on scientific performance, the weight of scientific discipline identity is slightly higher than that of scientific learning attitude. Hypotheses ⑦ and ⑧ are verified. Scientific discipline identification（β= 2.130, t=3.260***) has a significant positive direct effect on scientific thinking, thus confirming the hypothesis. Other variables, including teacher-student relationship, teacher teaching, and learning behavior, were not found to have a significant direct impact on scientific performance and scientific thinking, therefore the other hypotheses were not established.

There are other mediating effects in the model, such as teacher-student relationships（β= 0.322, t=6.828***) and teacher teaching methods（β= 0.305, t=5.428***) has a significant positive effect on scientific learning attitude, and the weight of teacher-student relationship is slightly higher than that of teacher teaching methods; Teacher-student relationship（β= 0.226, t=4.158***) and teacher teaching methods（β= 0.407, t=6.313***) has a significant positive impact on learning behavior, therefore hypotheses ② and ③ can be verified.

Table 3 Model Inspection Results

research hypothesis			**B**	**β**	**S.E.**	**t**
Scientific learning attitude	<---	teacher-student relationship	0.338	0.322	0.047	6.828***
Learning behavior	<---	teacher-student relationship	0.213	0.226	0.054	4.158***
Scientific learning attitude	<---	Teacher teaching	0.265	0.305	0.056	5.428***
Learning behavior	<---	Teacher teaching	0.318	0.407	0.065	6.313***
Scientific discipline identification	<---	teacher-student relationship	0.056	0.046	0.046	0.985
Scientific discipline identification	<---	Teacher teaching	0.059	0.058	0.055	1.056
Achievement	<---	Teacher teaching	-0.006	-0.099	0.931	-0.106
Scientific thinking	<---	Teacher teaching	0.058	0.722	0.731	1.011
Scientific thinking	<---	Learning behavior	0.048	0.466	0.632	0.737
Achievement	<---	Learning behavior	0.085	1.100	0.823	1.337
Achievement	<---	Scientific learning attitude	0.133	1.915	0.913	2.096*
Scientific thinking	<---	Scientific learning attitude	0.115	1.247	0.702	1.776
Achievement	<---	Scientific discipline identification	0.179	3.032	0.851	3.564***
Scientific thinking	<---	Scientific discipline identification	0.168	2.130	0.653	3.260***

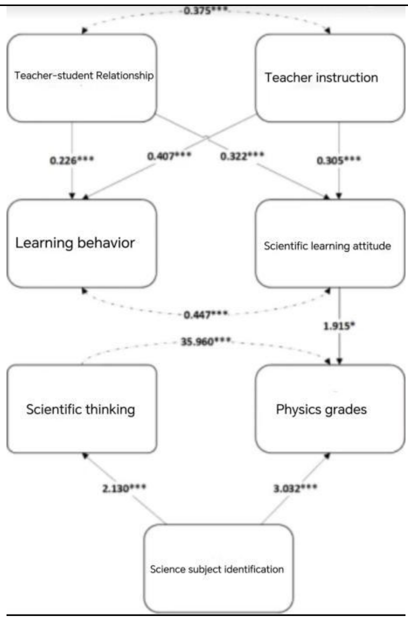

Figure 5 Model Path Result Graph

4.4 Quadrant distribution of scientific thinking and academic performance

When drawing the quadrant diagram in this study, the maximum score for scientific thinking was 54 points, and the scientific score was 100 points. The X-axis in the figure represents scientific thinking, while the Y-axis represents scientific performance. The first quadrant represents a relatively high level of scientific thinking and academic performance (SA * ST), while the second quadrant represents a relatively low level of scientific thinking and academic performance (SA *~ST); The third quadrant represents a relatively low level of scientific thinking and academic performance (~SA *~ST); The fourth quadrant represents (~SA * ST) with relatively high scientific thinking and relatively low scientific performance. The four quadrant distribution diagram of students' scientific thinking grades (relative) is as follows. The anchor points are designated according to the percentage of sample data distribution, and the values of 95%, 50%, and 5% are taken as three anchor points in ascending order; The three anchors of scientific thinking are 32, 15, and 1, and the three anchors of scientific achievement are 68, 44, and 22. From the results in the figure below, it can be seen that the distribution in the lower left and upper right corners is relatively dense, indicating that most students have the characteristics of high scientific thinking and good scientific performance, while low scientific thinking and poor scientific performance. (Dong Siyan,2022) This is consistent with Dong Siyan's research finding that there is a significant positive correlation between scientific thinking and academic performance (Dong Siyan, 2022).However, in this study, it was found that a portion of students were distributed in the second and fourth quadrants, indicating the phenomenon of high scientific thinking but poor grades (fourth quadrant), low scientific thinking but good grades (second quadrant).(Yang Haiyan,2021)Some studies have shown that students with scientific thinking abilities are more likely to understand and apply abstract concepts, and are better at analyzing and solving problems. These students are more inclined to use scientific methods for learning and research compared to taking exams (Yang Haiyan,2021), which seems to explain the reasons for the above phenomenon.

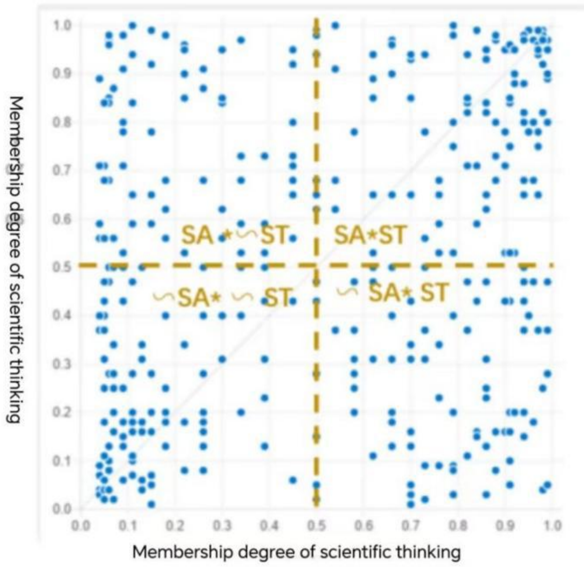

Figure 6 Quadrant distribution of students' scientific thinking and academic performance

5. Discussion and inspiration

5.1 High school students' scientific thinking ability is at a relatively low level, and implementing teaching to further achieve thinking development

The research results indicate that the majority of students' scientific thinking abilities are at low levels of 0 and 1, and the overall scoring rate of scientific thinking is less than 50%. Even in the dimension of "modeling metacognition and metamodeling knowledge", the scoring rate is only maintained at 23%, indicating that the current situation of high school students' scientific thinking abilities is not optimistic. Therefore, frontline teachers need to attach importance to students' scientific thinking and carry out targeted teaching based on their current situation. (Yu Shibo, Yu Haibo,2022) Firstly, physical concepts and laws are important ways to cultivate thinking. Teachers can start from two aspects: first, decompose complex concepts and laws to simplify them, and then integrate them; The second is visualization of thinking, using mind maps, flow charts, or fun equations to visualize the thinking process. Secondly, experiments are an important part of physics teaching, and teachers can start with scientific exploration.(Qi Zhanbo, Geng Xiangyi, Liu Yunfeng,2023) Advanced experiments are beneficial for enhancing students' personal experience, perception, and thinking, forming a series of thinking processes, enabling students to analyze problems with the knowledge they have learned, and construct physical models to solve problems. Therefore, teachers should establish a connection between experiments and thinking in teaching, promoting the development of students' scientific reasoning, argumentation, and modeling thinking. Finally, from the perspective of problem solving, teachers guide students to expand their problem-solving skills, providing multiple perspectives for problem-solving.(Shen Wei ,2022)At the same time, they gain insights into students' thinking and academic abilities through the generation process of different solutions. In addition, adapting and developing exercises to facilitate scientific thinking is also one of the ways to promote the development of students' scientific thinking.

5.2 Pay attention to the impact of scientific subject identification on scientific thinking ability, and attach importance to teacher-student relationships, teacher teaching, and scientific learning attitudes

From the model results, it can be seen that "scientific subject identification" has a direct and significant positive impact on students' scientific thinking, that is, the stronger their sense of subject identification, the higher their scientific thinking ability. One of the most direct ways to enhance students' scientific thinking ability is to create a positive emotional state when studying physics, enhance personal control and stability in learning and life, and provide students with high self-worth, enabling them to have a high level of scientific identity. From the model, it can be seen that there is a strong covariant relationship between physics grades and scientific thinking. Therefore, the improvement of physics grades is also one of the ways to develop scientific thinking ability. According to the path results, scientific learning attitude has a significant impact on physics grades. At the same time, teacher-student relationship and teacher teaching have a significant impact on scientific learning attitude. Therefore, teacher-student relationship, teacher teaching Scientific learning attitude is a few background factors that need to be focused on to enhance scientific thinking ability.

(Lei Hao, Wang Chenxin,2022) Firstly, sufficient allocation of teacher resources, moderate reduction of the student teacher ratio in the basic education stage, and optimization of the professional title structure of full-time teachers can effectively reduce the conflict and avoidance of teacher-student relationships, and deepen the teacher-student relationship.(Cui Yunguo, Lei Hao,2019)Secondly, in terms of teacher teaching, we need to deepen curriculum reform, change our mindset, and carry out large unit teaching designs that focus on core competencies.(Lei Hao,2021)We will focus on classroom teaching work around students learning how to learn, and(Lei Hao, Li Xue,2022)we will transform teaching evaluation methods around the implementation of competencies. (Luo Ronghua,2022) Finally, Chinese middle school students have a lower ranking in scientific attitudes and professional interests in the PISA assessment. On the one hand, we need to collaborate with various educational forces to accelerate the overall construction of science education. On the other hand, we need to improve classroom teaching methods and increase the participation of each student in science classrooms, thereby improving their scientific learning attitude.

5.3 Emphasize individual differences among students and achieve a balanced development of physics grades and scientific thinking

The research results show that the majority of students' scientific thinking ability is correlated with their physics grades, but there is still a phenomenon of imbalance between their scientific thinking ability and their physics grades. According to the characteristics of the data, class students can be roughly divided into the following five types: physics grades and scientific thinking are at a higher level in the class, physics grades and scientific thinking abilities are at a medium level, physics grades and scientific thinking are at a lower level in the class, physics grades are at a higher level in the class, but scientific thinking abilities are at a lower level in the class. The physics score is at a lower level in the class, but the scientific thinking ability is at a higher level in the class.(Lian Shuxiang,2019)Firstly, teachers can group each student according to their type. Group teaching is an effective teaching method that creates a learning atmosphere, promotes learning cooperation, and strengthens thinking and behavioral abilities. Members of each type of group communicate and discuss with each other, learn from each other's experiences, and help students of each type learn from each other, improve their physics grades, and scientific thinking. (Jiang Yonggui, Guo Yingdan, Zhao Bo, Xu Wangyi.,2022)Secondly, teachers can use their extracurricular time to conduct interviews with students of various types to understand their learning methods and habits, as well as the difficulties they face. They can provide certain learning suggestions for each person. At the same time, they can use their spare time to pay attention to the types of students whose physics grades and scientific thinking abilities are not balanced. For students with higher scientific thinking levels but lower physics grades, More inclined teaching of problem-solving skills; For students with higher physics scores but lower scientific thinking levels, teaching the essence of physics methods is more inclined. Finally, at the level of assigning homework, different types of homework are formed for each type of student, achieving a balanced development of physics grades and scientific thinking.

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