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Research on Educational Development Trends and Reform Pathways under the Guangdong-Hong Kong-Macao Education Cooperation Framework

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Abstract Educational cooperation and exchange between Guangdong, Hong Kong, and Macao have a long history. However, the Guangdong-Hong Kong-Macao Greater Bay Area, currently under construction, faces challenges such as insufficient awareness of the importance of educational cooperation and exchange, as well as a lack of innovative momentum. In light of these issues, this study proposes a reform pathway for educational cooperation within the Guangdong-Hong Kong-Macao educational cooperation framework. The research questions and hypotheses are identified, and based on relevant materials and literature, a survey questionnaire is developed. Subsequently, the questionnaire undergoes reliability and validity testing. Under the theoretical framework of the research design, an empirical exploratory analysis of educational reform pathways within the Guangdong-Hong Kong-Macao education cooperation framework is conducted. In terms of knowledge understanding and problem-solving abilities, the experimental group scored higher than the control group, and the difference was statistically significant at the 0.05 level. This indicates that compared to traditional educational methods, Guangdong-Hong Kong-Macao educational cooperation is more effective in enhancing students' knowledge understanding and problem-solving abilities, thereby demonstrating the practical application value of the Guangdong-Hong Kong-Macao educational reform pathways.

Index Terms Guangdong-Hong Kong-Macao, educational cooperation framework, reliability and validity testing, survey questionnaire

I. Introduction

The Guangdong-Hong Kong-Macao Greater Bay Area is an integral part of China's national strategic layout, comprising Hong Kong, Macao, and nine cities in Guangdong Province, encompassing the Hong Kong and Macao Special Administrative Regions as well as nine cities in the Pearl River Delta [1]-[3]. The Greater Bay Area serves as a pilot region for China's reform and opening-up initiatives and a key demonstration zone for the development of special economic zones under the new era of socialism with Chinese characteristics [4], [5]. The Guangdong-Hong Kong-Macao Greater Bay Area serves as a key window for China's opening-up to the outside world and also as a vital testing ground for domestic reforms [6], [7]. Its development strategy aims to create an engine for high-quality economic growth, a demonstration zone for scientific and technological innovation, a model area for deep integration between the mainland and Hong Kong and Macao, and a priority zone for economic cooperation and connectivity, thereby forming a modernized Greater Bay Area with strong comprehensive competitiveness [8]-[11]. As one of the key engines of China's economic development, the Greater Bay Area is not only collaborating on the economic front but also leveraging cooperation and innovation in the education sector as a core driver of regional development [12]-[14].

The Greater Bay Area boasts abundant educational resources, including numerous high-level universities and research institutions such as the Chinese University of Hong Kong, the Hong Kong University of Science and Technology, the University of Macau, Guangzhou University, and Shenzhen University [15]-[17]. These institutions of higher education possess unique advantages in research, talent cultivation, and international exchange, providing a solid foundation for regional educational cooperation [18], [19]. At present, educational cooperation in the Greater Bay Area primarily manifests across multiple levels, including higher education, vocational education, and basic education [20], [21]. In higher education, universities within the region actively engage in joint programs, degree recognition, and research collaboration to achieve resource sharing and complementary advantages [22], [23]. In basic education, localities have promoted the exchange of educational concepts and the innovation of teaching models through teacher exchanges and joint course development [24], [25]. Educational cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area holds significant meaning and value,

driving new trends in China's educational development and providing new pathways for educational reform [26], [27]. Under the framework of Guangdong-Hong Kong-Macao education cooperation, China's higher education is expected to develop toward optimizing resource allocation and enhancing educational quality. Through collaboration among higher education institutions, higher education resources can be integrated to achieve complementary advantages, improve teaching standards, and enhance research capabilities, thereby cultivating more and better talent for China [28]-[31].

Literature [32] introduces the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) and examines the background and characteristics of higher education development in the GBA using thematic analysis methods, pointing out that the development of higher education in the GBA has facilitated its transition from cooperation to strategic coordination and resource sharing. Literature [33] takes higher education cooperation as the research unit and policy changes as the research dimension to analyze the relevant policies of Guangdong-Hong Kong-Macao higher education cooperation, elucidating the overall trends and characteristics of policy changes in Guangdong-Hong Kong-Macao higher education cooperation. Literature [34] uses UCINET to construct a cooperation network among universities in the three regions based on cooperation data generated by multiple universities in the GBA, revealing that the current cooperation network density among GBA universities is high, but the trend of cohesion is not prominent. Literature [35] introduces the higher education background and cooperation status of major cities in the GBA, raises research questions, and highlights directions worthy of attention in future research. Literature [36] examines the opportunities, challenges, and contributions Hong Kong faces in promoting higher education internationalization within the GBA. Through a literature review, it demonstrates that Hong Kong's higher education sector can enhance its influence on the Guangdong-Hong Kong-Macao Greater Bay Area by exporting its educational programs and cultivating global talent. Literature [37] emphasizes that the GBA has set development goals to promote educational cooperation and build a talent hub, and points out that the key to achieving these goals lies in the development and deepening of cooperation in the higher education sector. Literature [38] highlights the important role of educational cooperation in the development of the GBA, noting that such cooperation requires balancing different priorities, such as short-term and long-term objectives, while considering institutional development and localized breakthroughs. Literature [39] examines the network patterns of collaborative paper publications among GBA universities and analyzes the quality and disciplinary distribution of these collaborative publications, indicating that the collaborative publication networks among GBA universities are dispersed and disciplinary development is uneven. Literature [40] points out that educational cooperation is an important component of the GBA's overall development strategy and analyzes the strengths and weaknesses of educational research in different regions, suggesting that educational research in various GBA regions should strengthen cooperation to achieve mutual benefits.

This paper takes the Guangdong-Hong Kong-Macao education cooperation framework as the starting point for this study, proposing a reform path for Guangdong-Hong Kong-Macao education from three aspects: national education, cultural adaptation, and educational funding investment. To demonstrate the practical value of the Guangdong-Hong Kong-Macao education reform pathways, an empirical research design was developed, research questions and hypotheses were established, and research participants were selected and grouped. To collect data for this study, a survey questionnaire was designed and validated for reliability and validity. After completing the preparatory work, the empirical analysis of the Guangdong-Hong Kong-Macao education reform pathways was formally conducted.

II. Research on the Development Trends and Reform of Education in Guangdong, Hong Kong, and Macao

II. A. Guangdong-Hong Kong-Macao Education Cooperation Framework

The Guangdong-Hong Kong-Macao Greater Bay Area comprises nine cities in the Pearl River Delta and two regions, Hong Kong and Macao. The “9+2” education cooperation framework is being developed through mutual adaptation [41]. Education cooperation among Guangdong, Hong Kong, and Macao is a process of transitioning from initial coordination to deeper integration. The three regions continuously plan cooperation directions, consolidate cooperation outcomes, streamline cooperation procedures, and continuously enhance education cooperation [42]. The specific details are as follows:

II. A. 1) Holistic Approach

Establishing a holistic concept of the Guangdong-Hong Kong-Macao Greater Bay Area requires the three regions of Guangdong, Hong Kong, and Macao to leverage their respective strengths, particularly their comparative advantages in education, through optimized integration to maximize the overall functionality. As a concept, the Greater Bay Area highlights the advantages of the three regions' education systems as an integrated sector on the global stage. This is based on the shared vision of Guangdong, Hong Kong, and Macao regarding education—a vision of consensus, coexistence, mutual prosperity, and symbiosis—and is focused on the construction of an education community of shared destiny within the Bay Area. The integration of Bay Area education implies that the development of education in Guangdong, Hong Kong, and Macao must not only move beyond the previous focus on individual interests and fragmented development but also align with national strategic objectives to achieve comprehensive cooperation and development aimed at building an internationally leading Bay Area. This

is achieved by establishing a "Bay Area consciousness," seeking common interests through complementary educational strengths among the three regions, establishing a platform for educational integration in the Bay Area, forming an integrated community of shared interests and development, and ultimately becoming an educational community of shared destiny to drive the comprehensive development of the Guangdong-Hong Kong-Macao Greater Bay Area.

II. A. 2) Principle of equality

Education in Guangdong, Hong Kong, and Macao differs in terms of development concepts, models, and quality standards. However, the parties involved in cooperation are equal, and the principle of equal status among education cooperation partners is a fundamental principle for establishing cooperative relationships. The various entities involved in Guangdong-Hong Kong-Macao education cooperation should respect one another without being bound by formalities and should not insist on strict reciprocity in all matters. Guangdong-Hong Kong-Macao education cooperation should redefine the principle of equality of status, abandoning face-saving, formalism, and bureaucracy, and instead establish the concept of "substantive equality based on respect" to avoid unnecessary constraints and achieve deep, substantive cooperation. In terms of equal cooperation among universities, the role of universities as the primary educational institutions should be emphasized. Hong Kong universities, Macao universities, and universities in the nine cities of the Pearl River Delta should be given more options in terms of "cooperation intentions," "cooperation models," "cooperation processes," and "cooperation content," thereby achieving true educational equality and cooperation.

II. A. 3) Asymmetry

If there is a direct conflict within a cooperative system, and this conflict does not lead to the collapse of the cooperative system, then asymmetry and uncertainty simultaneously explain the diversity of cooperative behavior and strategies within the cooperative system. In other words, in a stable cooperative system, the costs and benefits of cooperation, as well as the number of individual participants, can be unequal. If the three regions of Guangdong, Hong Kong, and Macao adopt a narrowly self-interested stance, overly focusing on costs and benefits and insisting that the other party accept their own ideas, this will be detrimental to practical cooperation in education among the three regions. For example, in educational cooperation among the three regions, when exchanging scholars and students, both sides do not necessarily need to emphasize reciprocity, i.e., the number of teachers or students each side sends. Jointly funded schools do not necessarily require both sides to contribute 50% of the operational funds. In academic exchange cooperation, the ideal scenario is mutual visits and exchanges, but it can also involve one-sided visits or exchanges. A comprehensive cooperation framework encompassing multiple projects does not necessarily need to be perfectly balanced or symmetrical.

II. B. Development Path

II. B. 1) National Education

National education refers to the education implemented by the state to help students understand the true state of the nation, strengthen patriotic sentiments and national pride among young people, and foster students' civic awareness and participatory capabilities. Its core is national identity, which refers to the cognitive and emotional recognition of citizens belonging to the political community of their homeland. The most important function of national identity is to provide a powerful "historical and destiny community," thereby rescuing people from the abyss of individual annihilation and reshaping collective faith. In other words, national education is closely related to citizens' identity recognition, ethnic perspective, national perspective, and values. National education can enable young people from Hong Kong and Macao to gain a deeper understanding of the history, culture, and political system of the mainland. This humanistic, firsthand experience resonates more deeply with people's hearts than economic interests, and can enhance young people's sense of national identity and ethnic pride, thereby strengthening the public foundation for educational exchange and cooperation. Undoubtedly, this is highly beneficial for promoting educational cooperation and development in the Guangdong-Hong Kong-Macao Greater Bay Area.

II. B. 2) Building a mechanism for students to adapt to academic culture

According to statistics, among universities in mainland China, Jinan University alone has had over 58,000 Hong Kong students and nearly 27,500 Macau students enrolled, with 6,180 Hong Kong students and 1,890 Macau students currently still enrolled. Due to differences in educational systems and philosophies between mainland China and Hong Kong/Macao, Hong Kong/Macao students face challenges in adapting to course structures, teaching content, teaching methods, and campus culture after enrolling in mainland institutions, and may even experience "soft cultural conflicts" to some extent. Therefore, establishing effective academic and psychological support mechanisms for Hong Kong/Macao students to help them smoothly enroll and adapt to campus culture in mainland China is the most fundamental measure to promote the development of education cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area. Strengthening the mechanisms for academic and cultural adaptation for Hong Kong and Macao students in mainland China is not only the cornerstone for promoting

educational cooperation and development in the Guangdong-Hong Kong-Macao Greater Bay Area but also a necessary condition for deepening such cooperation. For Hong Kong and Macao students, their educational experience in mainland China is not only a process of completing their studies but also an important opportunity to develop a sense of belonging to their homeland.

II. B. 3) Establishment of a mechanism for sustained investment in education cooperation funds

Education cooperation and development in the Guangdong-Hong Kong-Macao Greater Bay Area encompasses all aspects of education across the three regions, covering a wide range of fields and involving numerous initiatives. This includes higher education cooperation such as joint university programs, co-built laboratories, and the development of flagship disciplines, as well as vocational education initiatives related to admissions, employment, and training. Additionally, in the field of basic education, Guangdong has established Hong Kong and Macao Children's Classes for students from Hong Kong and Macao and provides boarding services, among other institutional arrangements. However, whether the existing educational resources in the nine cities of the Pearl River Delta region within the Bay Area can support the influx of Hong Kong and Macao residents coming to the mainland for education remains a question. Surveys indicate that due to the shortage of public school seats, cities across the Pearl River Delta have adopted a points-based admission system to set admission thresholds. In some cities, the overall pass rate for non-local household students ranges from 1/6 to 1/4, leaving the children of Hong Kong and Macao residents or those working in the Bay Area facing difficulties in accessing quality education. Therefore, increasing education funding, establishing more public schools, improving boarding conditions at existing schools, and introducing more high-quality educational resources to attract young people from Hong Kong and Macao to study in the region, ensuring they can access quality educational resources within the Bay Area, will be the sustainable path to ensuring and promoting the development of education cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area.

III. Study Design

As mentioned above, in order to meet the learning needs of students in the Guangdong-Hong Kong-Macao Greater Bay Area, three educational reform pathways have been proposed under the Guangdong-Hong Kong-Macao Greater Bay Area Education Cooperation Framework. To further validate the practical application value of these educational reform pathways, this chapter outlines a corresponding research plan. Details are as follows:

III. A. Research Questions and Hypotheses

III. A. 1) Research Questions

Under the influence of Guangdong-Hong Kong-Macao cooperation in education, education scholars are seeking teaching models suitable for students in the Guangdong-Hong Kong-Macao region. To truly transition Guangdong-Hong Kong-Macao cooperation in education from concept to practice, it is necessary to overcome the entrenched mindsets and practices of traditional teaching, conduct research on Guangdong-Hong Kong-Macao cooperation in education, and place greater emphasis on students' learning needs, learning processes, and capabilities. Therefore, this experimental study poses the following four questions regarding the effectiveness of Guangdong-Hong Kong-Macao cooperation in education:

(1) Does Guangdong-Hong Kong-Macao collaborative education have an impact on students' understanding of scientific knowledge?

(2) Does Guangdong-Hong Kong-Macao collaborative education have an impact on cultivating students' problem-solving abilities?

(3) Compared to traditional education, does Guangdong-Hong Kong-Macao collaborative education result in differences in students' understanding of scientific knowledge?

(4) Compared to traditional education, does Guangdong-Hong Kong-Macao collaborative education result in differences in enhancing students' problem-solving abilities?

III. A. 2) Research Hypothesis

Based on the four research questions described above, this section proposes two research hypotheses. Specifically, they are as follows:

(1) Compared with traditional education methods, Guangdong-Hong Kong-Macao cooperation in education is more effective in cultivating students' problem-solving abilities.

(2) Compared with traditional education methods, Guangdong-Hong Kong-Macao cooperation in education can better improve students' understanding of scientific knowledge.

III. B. Experimental Design

This experimental study mainly consists of six steps, the specific details of which are as follows:

(1) Conduct an analysis of the learning situation of fifth-grade students, select the “Circuits” unit, and design the teaching

content of the "Circuits" unit in combination with the Guangdong-Hong Kong-Macao education cooperation framework and small curriculum standards.

(2) Conduct multiple discussions and analyses with subject experts and science teachers, revise the curriculum content arrangement, and improve the unit teaching design based on the science teachers' trial teaching of the curriculum to form the final teaching unit.

(3) The research questions were determined, and pre- and post-test questionnaires were developed. These were discussed multiple times with subject experts and science teachers to form a draft version of the questionnaires.

(5) A total of 40 students with comparable academic levels were selected as research subjects from the Guangdong-Hong Kong-Macao region, including 20 in the control group and 20 in the experimental group. The control group students received traditional education for 12 class periods. The experimental group students followed the Guangdong-Hong Kong-Macao educational pathway designed in this study for 12 class periods.

(6) Both the control group and the experimental group underwent pre- and post-test assessments of course learning, with data collected, organized, and analyzed. The experimental research conclusions were drawn based on the results of the data analysis.

This experimental study primarily measured and evaluated the effectiveness of the Guangdong-Hong Kong-Macao education pathway from two aspects: the acquisition of scientific knowledge and the development of problem-solving abilities.

(1) In terms of knowledge acquisition, paired-sample t-tests were conducted on the knowledge dimension to compare the pre- and post-test results of the control group and the experimental group [43].

(2) In terms of problem-solving ability development, paired-sample t-tests were conducted on the problem-solving ability dimension to compare the pre- and post-test results of the control group and the experimental group.

(3) For the post-test data, independent samples t-tests were conducted on the overall questionnaire, knowledge dimension, and problem-solving ability dimension to compare the differences between the control group and the experimental group.

(4) For the post-test data on problem-solving ability, independent samples t-tests were conducted on different types of problems to compare the differences between the control group and the experimental group in terms of problem-solving ability.

III. C. Development and validation of pre- and post-test questionnaires

III. C. 1) Development of pre- and post-test questionnaires

The pre- and post-test questionnaires have the same content, primarily consisting of two sections: science knowledge test questions and problem-solving ability test questions. The science knowledge test questions correspond to questions 1–6 on the questionnaire, with each question worth 3 points. The problem-solving ability test questions correspond to questions 7–12 on the questionnaire, with decision-making questions being questions 7 and 8, where question 7 is worth 6 points and question 8 is worth 8 points. Design and analysis-related questions are questions 9 and 10, each worth 10 points. Troubleshooting-related questions are questions 11 and 12, each worth 14 points. The scientific knowledge test section was designed based on the science curriculum standards, while the problem-solving ability test section was designed based on the science curriculum standards, the essence of problem-solving, and problem classification. Through discussions with multiple experts and science teachers, the questionnaire was gradually finalized.

III. C. 2) Questionnaire validity and reliability testing

(1) Reliability Analysis

This study used Cronbach's alpha coefficient as a reliability indicator to measure the internal consistency of the questionnaire and conduct reliability testing. The internal consistency coefficient (Cronbach's alpha) refers to the consistency among the items in the questionnaire. This questionnaire includes two dimensions: knowledge and problem-solving ability. Therefore, internal consistency analysis was conducted separately for knowledge and problem-solving ability. As shown in Table 1, based on the results of the SPSS analysis, the Cronbach's alpha for the entire questionnaire, the knowledge dimension, and the problem-solving ability dimension were all greater than 0.8, indicating that the reliability of the questionnaire is relatively high.

Table 1: Internal consistency coefficient of the questionnaire

Project	Cronbach's Alpha	Based on standardized items Cronbach's Alpha	Number of items	Number of people
The entire questionnaire	0.812	0.844	12	40
Knowledge	0.888	0.877	6	40
Problem-solving ability	0.835	0.835	6	40

(2) Validity Analysis

This primarily evaluates the content validity of the questionnaire. Content validity refers to whether the designed questions can represent the content or theme to be measured, and is often assessed using a combination of logical analysis and statistical

analysis. Experts and science teachers evaluated the questions designed in this questionnaire and determined that they align with the measurement objectives and requirements. Statistical pre-experiments were conducted to calculate students' individual scores and total scores, and the correlation between individual scores and total scores was tested. The SPSS statistical results are shown in Tables 2 and 3. As shown in Tables 2 and 3, the content-relatedness between the knowledge questions and problem-solving questions in the questionnaire is significant, and they align with the measurement objectives and requirements.

Table 2: Validity of each question in the knowledge dimension

Project	Number of people	Pearson Relevance	Sig.
1	40	0.867**	0.0001
2	40	0.828**	0.0002
3	40	0.827**	0.0004
4	40	0.808**	0.0005
5	40	0.607**	0.0003
6	40	0.787**	0.0006

Table 3: Problem-solving ability dimension validity of each question

Project	Number of people	Pearson Relevance	Sig.
7	40	0.606**	0.0001
8	40	0.456**	0.0002
9	40	0.668**	0.0004
10	40	0.706**	0.0005
11	40	0.795**	0.0003
12	40	0.794**	0.0006

(3) Item Analysis

Item analysis primarily includes difficulty analysis and discrimination analysis. The metric for difficulty analysis is the difficulty coefficient, which for subjective questions is the ratio of the average score per question to the total score for that question. The metric for discrimination analysis is the CR value for each question; if the CR value reaches the 0.05 significance level, the item is retained. The specific steps are as follows: first, calculate the total score for each participant's questionnaire, then divide the scores into high and low groups based on the top and bottom 30%, and finally perform an independent samples t-test on each question to detect differences in the average scores. The difficulty coefficients of the questionnaire are shown in Figure 1, and the results of the item analysis are presented in Table 4. Most questions have moderate difficulty, but the third question in the problem-solving dimension (i.e., question 9 in the questionnaire) has a relatively low difficulty coefficient. This may be because this question is a design and analysis-type problem that also assesses knowledge of parallel circuits. However, traditional inquiry-based courses rarely focus on students' learning of such problems, and parallel circuits are relatively challenging for elementary school students, so this result is reasonable. Each question has significant discriminative power and high reliability, effectively assessing students' understanding of knowledge and problem-solving abilities.

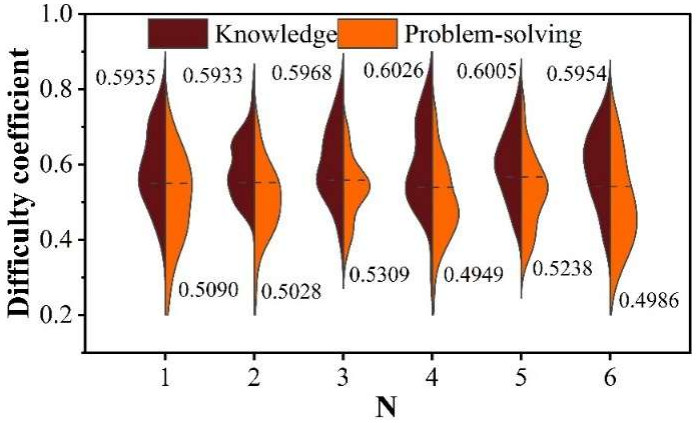

Figure 1: The difficulty coefficient of the questionnaire

Table 4: The project analysis results of the questionnaire

Project	Number of people	Average value	F-test	Sig.
1	40	3.013	23.27	0.004
2	40	3.537	24.07	0.007
3	40	4.245	57.39	0.006
4	40	4.291	24.39	0.003
5	40	4.885	7.49	0.006
6	40	5.665	61.17	0.003
7	40	7.479	7.11	0.005
8	40	7.88	4.42	0.007
9	40	8.798	30.26	0.009
10	40	9.933	121.08	0.007
11	40	10.371	14.28	0.002
12	40	10.926	31.12	0.007

IV. Empirical Research Analysis

IV. A. Analysis of Differences in Knowledge Understanding

IV. A. 1) Analysis of results before intervention between groups

Before conducting the teaching experiment, the author distributed pre-test questionnaires to students in the experimental group and control group, who were required to complete them within 18 minutes, after which the questionnaires were collected. A T-test was conducted using SPSS to compare the knowledge comprehension scores of students in the control group and experimental group and determine whether there were any differences between them. The test results are shown in Figure 2, where EG and CG represent the experimental group and control group, respectively. The mean pre-test scores for knowledge understanding in the experimental group were 67.37, with a standard deviation of 0.187. The mean pre-test scores for knowledge understanding in the control group were 67.42, with a standard deviation of 1.0 ($t = 0.136$, $P > 0.05$). This indicates that there is no significant difference in test scores between the pre-test of the experimental group and the pre-test of the control group, meaning that there is no significant difference in the knowledge comprehension levels of the students in the experimental group and the control group. Therefore, experiments can be conducted on the experimental group and the control group respectively based on this foundation.

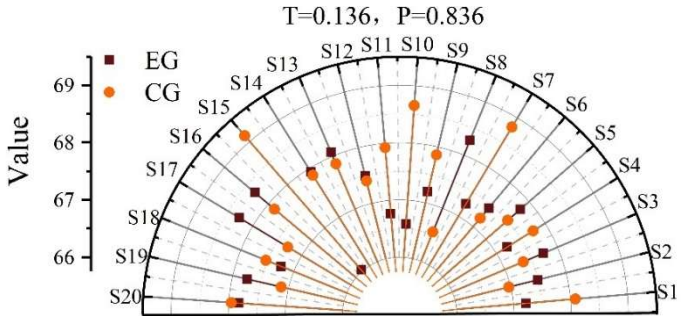

Figure 2: Inspection results

IV. A. 2) Analysis of results before and after intervention in the experimental group

This test consists of 12 questions, which students are required to complete within 20 minutes. A T-test was conducted on the pre-test and post-test scores of the experimental group based on the test results. The analysis of the experimental group's results after the intervention is shown in Figure 3. The results show that the mean score for knowledge understanding in the pre-test of the experimental group was 67.37, with a standard deviation of 0.187. The mean score for the post-test of the experimental group was 76.35, with a standard deviation of 0.583 ($t = -24.456$, $P < 0.05$). This indicates a significant difference in knowledge understanding scores between the pre-test and post-test of the experimental group. Based on the test results, the Guangdong-Hong Kong-Macao education reform path proposed in this paper has played a positive role in cultivating and improving students' knowledge comprehension abilities.

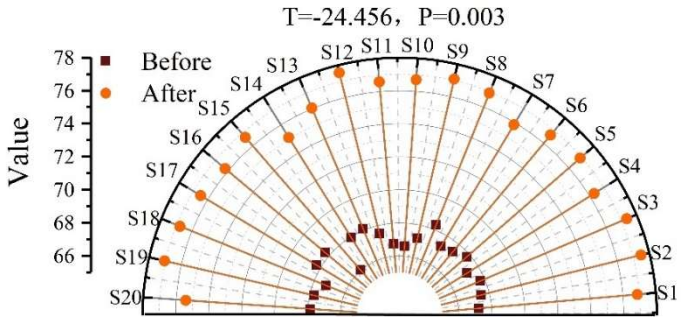

Figure 3: Analysis of the results after the intervention in the experimental group

IV. A. 3) Analysis of results before and after intervention in the control group

Figure 4 shows the results of the comparative analysis of differences in students' knowledge understanding scores between the pre-test and post-test of the control group. The mean score for the pre-test in the control group was 67.42, with a standard deviation of 1.0. The mean score for the post-test in the control group was 68.85, with a standard deviation of 0.47. This indicates that there is no significant difference in students' knowledge comprehension scores between the pre-test and post-test in the control group ($t = -1.482$, $P > 0.05$). The results of the pre-test and post-test in the control group indicate that traditional educational methods have a limited effect on the development of students' knowledge comprehension abilities.

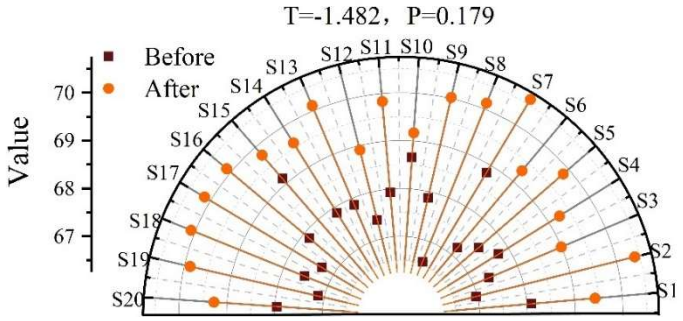

Figure 4: Analysis of the results after intervention in the control group

IV. A. 4) Analysis of results after intergroup intervention

Building on the preceding discussion, we utilized SPSS software to investigate the post-intervention outcomes of knowledge comprehension scores between groups. Figure 5 presents the results of the post-intervention difference analysis between the experimental group and the control group. The data show that the mean score of the experimental group after the intervention was 76.35, with a standard deviation of 0.583, while the mean score of the control group after the intervention was 68.85, with a standard deviation of 0.47 ($t = 13.126$, $P < 0.05$). This indicates that there is a significant difference in scores between the experimental group and the control group after the intervention. The difference in post-test scores between the experimental group and the control group also indicates that teaching using the Guangdong-Hong Kong-Macao education development approach has played a certain role in cultivating students' knowledge comprehension abilities. It also confirms the aforementioned hypothesis (that Guangdong-Hong Kong-Macao cooperative education can better enhance students' scientific knowledge comprehension abilities compared to traditional educational methods).

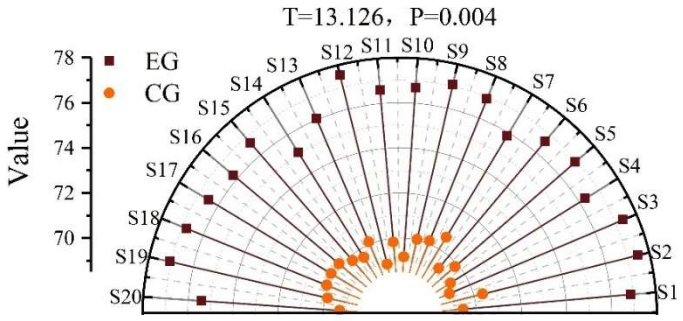

Figure 5: Analysis of the results after inter-group intervention

IV. B. Analysis of Differences in Problem-Solving Abilities

IV. B. 1) Comparative analysis of student data between the two groups before and after the experiment

The comparison of problem-solving abilities between the two groups of students before the experiment is shown in Table 5. Before the experiment, the problem-solving abilities of the two groups of students were tested. Through data analysis, it was found that the P-values for problem-solving ability, attitude toward problems, methods of addressing problems, and quality of problem-solving were all greater than 0.05 for both groups. This indicates that there were no significant differences between the experimental group and the control group, making them comparable and suitable for a controlled experiment. From the data, it can be observed that the experimental group outperformed the control group in problem-solving ability (91.338 > 90.45), problem-solving methods (23.306 > 23.083), and problem-solving quality (40.292 > 39.45). However, in terms of attitude toward problem-solving (27.242 < 27.416), the control group outperformed the experimental group.

Table 5: Comparison of Students' problem-solving abilities before the experiment

Variable	EG (N=20)		CG (N=20)		T-Value	P-Value
	Mean	SD	Mean	SD		
Problem-solving ability	91.338	23.401	90.45	14.183	0.147	0.869
Attitude towards problem-solving	27.242	7.292	27.416	3.416	-0.219	0.816
The method of problem-solving	23.306	6.338	23.083	4.425	0.289	0.759
The quality of problem-solving	40.292	10.192	39.45	6.366	0.306	0.756

The comparison of problem-solving abilities between the two groups of students after the experiment is shown in Table 6. After the experiment, the problem-solving abilities of the two groups of students were tested. Through data analysis, it was found that the P-values for the two groups of students in terms of problem-solving attitude, problem-solving methods, and problem-solving quality were all greater than 0.05, indicating that there were no significant differences between the experimental group and the control group. However, the P-value for problem-solving methods was less than 0.05, indicating a significant difference. From the data, it can be seen that the experimental group outperformed the control group in problem-solving ability (99.226 > 96.161), problem-solving attitude (29.322 > 29.066), problem-solving methods (26.436 > 24.461), and problem-solving quality (42.468 > 42.083).

Table 6: Comparison of students' problem-solving abilities after the experiment

Variable	EG (N=20)		CG (N=20)		T-Value	P-Value
	Mean	SD	Mean	SD		
Problem-solving ability	99.226	16.13	96.161	10.127	0.461	0.356
Attitude towards problem-solving	29.322	4.458	29.066	3.046	0.242	0.615
The method of problem-solving	26.436	3.369	24.461	3.134	2.076	0.018
The quality of problem-solving	42.468	8.312	42.083	5.009	0.212	0.336

Overall, compared with traditional educational methods, the Guangdong-Hong Kong-Macao educational approach proposed in this paper has a more significant effect on improving students' problem-solving abilities. In addition, it confirms the research hypothesis proposed above (that Guangdong-Hong Kong-Macao cooperative education has a more significant effect on cultivating students' problem-solving abilities than traditional educational methods).

IV. B. 2) Comparative analysis of problem-solving abilities between the two groups of students

A comparative analysis of problem-solving abilities between the two groups of students is shown in Table 7. The data indicate that the problem-solving abilities of both groups of students improved to some extent before and after the experiment. Before and after the experiment, the P-value between the experimental group and the control group was less than 0.05, indicating a significant difference in problem-solving abilities between the two groups before and after the experiment. Compared with traditional educational methods, the Guangdong-Hong Kong-Macao cooperation educational approach can enhance students' problem-solving abilities. Teaching activities are centered around “problems,” with students at the core. Each student can analyze the scenarios in teaching activities, pose questions, make hypotheses, and verify those hypotheses. During the specific problem-solving process, guided by teachers and teaching activities, students gradually master the steps of problem-solving and construct their own methods for analyzing and solving problems.

Table 7: Comparative analysis of problem-solving abilities

Group		Problem-solving ability	T-Value	P-Value
EG	Before	91.338±23.401	-4.383	0.005
	After	99.226±16.13		
CG	Before	90.45±14.183	-4.434	0.003
	After	96.161±10.127		

IV. B. 3) Comparative analysis of problem-solving attitudes between the two groups of students

The problem-solving attitudes of the two groups of students were tested before and after the experiment. The comparison results of the problem-solving attitudes between the two groups are shown in Table 8. The data indicate that the P-value for the problem-solving attitudes between the experimental group and the control group is less than 0.05, indicating a significant difference between the two groups before and after the experiment. Due to their weak foundational knowledge, students generally perform poorly academically and have a low sense of presence in high school classrooms. They exhibit low levels of interest in learning, are not actively engaged in classroom activities, and tend to avoid problems. Introducing the Guangdong-Hong Kong-Macao cooperation education model into the classroom, which reduces the teacher's dominant role and positions each student as the central figure in teaching activities, can stimulate students' enthusiasm for classroom participation, foster a more proactive and active mindset toward problem-solving, and enhance their courage to confront challenges.

Table 8: Comparative Analysis of Problem-solving attitudes

Group		Attitude towards problem-solving	T-Value	P-Value
EG	Before	27.242±7.292	-3.116	0.006
	After	29.322±4.458		
CG	Before	27.416±3.416	-4.195	0.001
	After	29.066±3.046		

IV. B. 4) Comparative analysis of problem-solving methods between the two groups of students

Using the same method, the problem-solving approaches of the two groups of students were tested. The comparison results of the problem-solving approaches between the two groups are shown in Table 9. It was found that the P-value between the experimental group and the control group was less than 0.05, indicating a significant difference in problem-solving approaches between the two groups before and after the experiment. Students generally exhibit a lack of enthusiasm for learning, have poor initiative in their studies, and lack advanced cognitive strategies such as learning strategies. The fundamental reason for this is insufficient investment in learning and a lack of self-reflection. The Guangdong-Hong Kong-Macao cooperation education pathway guides students to engage in learning activities along the main thread of identifying problems, analyzing problems, solving problems, and summarizing problems. Students come to recognize the importance of methods and gradually develop their own set of problem-solving methods and strategies.

Table 9: Comparison of students' problem-solving methods

Group		Problem-solving methods	T-Value	P-Value
EG	Before	23.306±6.338	-4.063	0.001
	After	26.436±3.369		
CG	Before	23.083±4.425	-4.064	0.005
	After	24.461±3.134		

IV. B. 5) Comparative analysis of problem-solving qualities between the two groups of students

Table 10 presents a comparative analysis of problem-solving quality between the two groups of students. The comparative analysis reveals that the P-value for problem-solving quality between the experimental group and the control group is less than 0.05, indicating a significant difference in problem-solving quality between the two groups before and after the experiment. Students have weak knowledge levels and limited problem-transferring abilities. Their learning mindset remains at the stage where teachers impart knowledge and students passively absorb it. After introducing the Guangdong-Hong Kong-Macao cooperation education pathway, teachers guide students to summarize problem-solving processes and construct knowledge. Through internal or inter-group exchanges and evaluations, students learn excellent methods and techniques from other group members, apply these techniques to their own problem-solving processes, and optimize their problem-transferring

and summarizing abilities through mutual learning. This enables them to innovate their problem-solving methods and enhance their problem-solving capabilities.

Table 10: Comparative Analysis of Students' Problem-solving Qualities

Group		Problem-solving quality	T-Value	P-Value
EG	Before	40.292±10.192	-4.495	0.006
	After	42.468±8.312		
CG	Before	39.45±6.366	-4.005	0.009
	After	42.083±5.009		

V. Conclusion

Educational cooperation in the Guangdong-Hong Kong-Macao Greater Bay Area still faces challenges such as insufficient problem-solving abilities and inadequate knowledge comprehension among students. In response, this study proposes an educational reform framework under the Guangdong-Hong Kong-Macao educational cooperation framework and validates its practical application effectiveness, designing a corresponding validation research plan. Under the theoretical guidance of this plan, an empirical investigation of the Guangdong-Hong Kong-Macao educational framework was conducted. Analysis reveals that there are significant differences ($P<0.05$) between traditional education and Guangdong-Hong Kong-Macao education in terms of students' knowledge comprehension and problem-solving abilities. This not only validates the research hypotheses proposed in this paper but also confirms the practical application value of the reform pathways under the Guangdong-Hong Kong-Macao education cooperation framework.

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