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Research on the development path of "stem +" education based on digital visualization and virtual reality

Xiaoqian Li[1,✉]

[1] *Institute of Education-Industry Synergy for Talent Development, University of Sanya, Sanya, Hainan, 572022, China*

ABSTRACT

STEM education emphasizes the in-depth integration between the knowledge of different disciplines, which is based on real problem solving, aims to establish an organic link between education and life, and takes the cultivation of composite talents with a sense of innovation and hands-on ability as the fundamental purpose. Aiming at the current problems of STEM education, the development path of STEM+ education based on digital visual virtual reality is proposed. Then, combining the DEMATEL method and Interpretive Structural Modeling (ISM), the dynamic factors affecting the development of STEM+ education are explored. Finally, the fuzzy set qualitative comparative analysis (fs/QCA) method was used to analyze the group path of STEM+ education high-quality development. The results of the analysis of motivational factors show that the governmental promotion among the extrinsic motivational factors has a high centrality and is a deep factor that drives the development of STEM+ education. Synergistic motivational factors play the largest role among the three dimensions and are the key to ensure the development of STEM+ education. Endogenous motivational factors are the direct motivational factors for the development of STEM+ education and need to be focused on control. The analysis of the grouping paths in region C, for example, shows that there are two high-level grouping paths and three non-high-level grouping paths, multiple grouping paths with different paths, and high-level grouping and non-high-level grouping are in an asymmetric state. There are some differences in the grouping paths in the east, center and west, and the three regions' high-quality development of STEM+ education cannot be separated from the support of state factors and response factors. This paper provides a path reference for realizing high-level STEM+ education high-quality development.

Keywords: dematel, explanatory structural model, fs/QCA, STEM+ education

1. Introduction

STEM education is an interdisciplinary and integrated educational model that integrates four different

✉ Corresponding author.
E-mail address: 18889831367@163.com (X. Li).

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fields of science, technology, engineering, and mathematics, aiming to cultivate complex human resources with innovative and critical thinking [1-3]. In order to incorporate technology and engineering into the regular curriculum, STEM education creates a “meta-science” that revolutionizes the teaching of math and science. In order to advance STEM education, it is critical to develop appropriate strategies and implementation pathways [4-7].

The promotion of STEM education requires the cooperation of the education sector. Education departments at all levels can formulate policies and outlines for STEM education to ensure that STEM education can receive adequate resources and support [8-10]. At the same time, cooperation with related industries and research institutions to carry out practical projects and scientific research activities, promote the deep integration of education and industry, and provide better learning opportunities for students [11-13]. The success of STEM education is closely related to the quality of teachers. Teachers need to have solid subject knowledge and skills, as well as mastering relevant technologies such as scientific experimentation, engineering design and programming. Therefore, providing high-quality teacher training is an important part of implementing STEM education [14-17]. Education departments and schools can organize relevant trainings and seminars to provide the latest teaching resources and methods to help teachers enhance their competence in STEM education [18-20]. STEM education emphasizes the active participation of students and the cultivation of their practical abilities, therefore, innovative teaching methods are crucial for the implementation of STEM education. The use of heuristic teaching, project-based learning and teamwork can stimulate students' interest and creativity, and cultivate their scientific thinking and problem-solving abilities [21-24].

Taking the problems of STEM education as the starting point, this paper designs an optimized STEM+ education development path based on digital visual virtual reality technology in terms of multidisciplinary knowledge linkage, problem chain teaching, teacher's professional ability, and three-dimensional learning environment. At the same time, the power mechanism of STEM+ education development was explored in terms of endogenous, external and synergistic dynamics using the DEMATEL-ISM method. In addition, an empirical study was conducted using the QCA method, based on the DPSIR framework, and the grouping path of high-quality development of STEM+ education was analyzed with the level of high-quality development of STEM+ education as the outcome variable, and the five elements of drive, pressure, state, and influence and response as the conditional variables.

2. STEM+ education development path based on digital visualization virtual reality

Aiming at the problems of planarization, formalization, superficialization and scarcity that exist in the current STEM education, this paper proposes a path for the development of STEM education based on digital visual virtual reality.

2.1. Introducing “big idea” multidisciplinary knowledge linkages

The “big concept” is a superordinate concept that points to the structure of disciplinary knowledge, covers the horizontal connection between knowledge of different disciplines and the vertical connection of knowledge within disciplines, and is unifying, generalizing and expanding in nature. Its core purpose is to condense the structure of disciplinary knowledge, grasp the intrinsic links between different knowledge and organize it according to a certain logic.

The big concept has the characteristics of “centrality”, “dynamics” and “hierarchy”, and its content is very suitable for the concept of interdisciplinary integration of STEM education, which provides a practical basis for the development of STEM education. It provides a practical basis for the development of STEM education. The application areas of the Big Concept in STEM education are reflected in the following aspects:

1) Designing scientific problems from the structure of disciplinary knowledge, guaranteeing the

interdisciplinarity, inferiority, representativeness, and sequentiality of the problems.STEM education starts from the driving problems, and the sequentiality of the problem design is the key issue. The structure of the horizontal and vertical networks presented according to the big concepts helps to prioritize the questions. This problem sequencing relationship can be depicted by three mutually nested circles as shown in Figure 1.

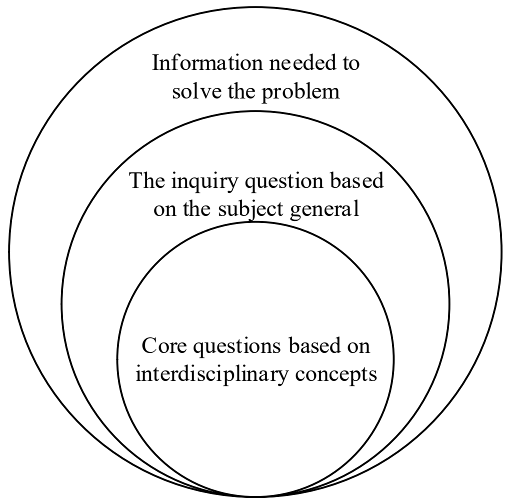

Fig. 1. Prioritization model of STEM education issues based on big concepts

2) From the perspective of skill cultivation, it promotes the transfer and application of knowledge. The Big Concept organizes fragmented multidisciplinary concepts and information into a dynamic network of STEM concepts and continuously spreads outward, which not only establishes a clearer organic connection between old and new knowledge, makes the hierarchy clearer and easier to understand, but also effectively changes the previous solid and rigid knowledge system, and promotes the migration of knowledge.

2.2. Problem leading based on problem chaining instruction

Problem chain teaching is to transform the teaching content into a problem that can be thought and solved, and to design systematic inquiry activities to drive students to carry out in-depth exploration and divergent thinking, and to gradually complete the understanding of knowledge and experience in the process of solving problems, which can help to cultivate students' problem-solving ability and higher-order thinking ability. The arrangement of different problems in the problem chain is not disorganized, but presents certain inner connections and hierarchical relationships under the guidance of disciplinary core thinking, reflecting the basic logic of the operation and development of multidisciplinary knowledge.

This study combines the big concept-based problem prioritization model of STEM education, the interdisciplinary integration of STEM education and the characteristics of problem chain teaching, and constructs a problem chain teaching framework for STEM education as shown in Fig. 2, which is based on the main line of disciplinary core thinking, oriented by the function of the problem, and focusing on the inquiry experience.

Problem chain teaching subdivided the teaching content into four types of main questions: retrospective questions, guiding questions, extended questions and summarizing questions. These four types of questions cascade and interact with each other, and together they form the problem chain in STEM education.

First are the retrospective questions. As the starting point of the whole problem chain, these questions are put forward by the teacher according to a certain situation, which are mainly used to review what has been learned, help students establish the connection between new and old knowledge, and can naturally transition to the next category of questions.

The second is guiding questions. These questions serve as the foundation of the entire question chain and are actually the beginning of the new content being learned. Guiding questions are the core questions based on cross-disciplinary big ideas and inquiry questions based on disciplinary big ideas in the STEM education question prioritization model. In response to these questions, students are guided by the teacher to gather information, think deeply, and conduct practical inquiry.

Once again, there are extended questions. As the key to the whole chain of questions, these questions serve to allow students to conduct deeper thinking and inquiry, and to systematically analyze and understand the application from multiple perspectives, in order to further develop students' higher-order thinking. Extended questions are spontaneously proposed by students in the learning process, under the guidance of teachers, as their thinking deepens, along the generative pulse of subject knowledge.

Finally, there are summarizing questions. This type of problem is based on the retrospective questions, guiding questions and extended questions, after refining and summarizing, put forward more general and broadening the problem, so that students form a deeper understanding, which often puts forward a higher demand for thinking skills. Summarizing questions are guided by the core thinking of the subject and are put forward jointly by teachers and students to stimulate further thinking and inquiry.

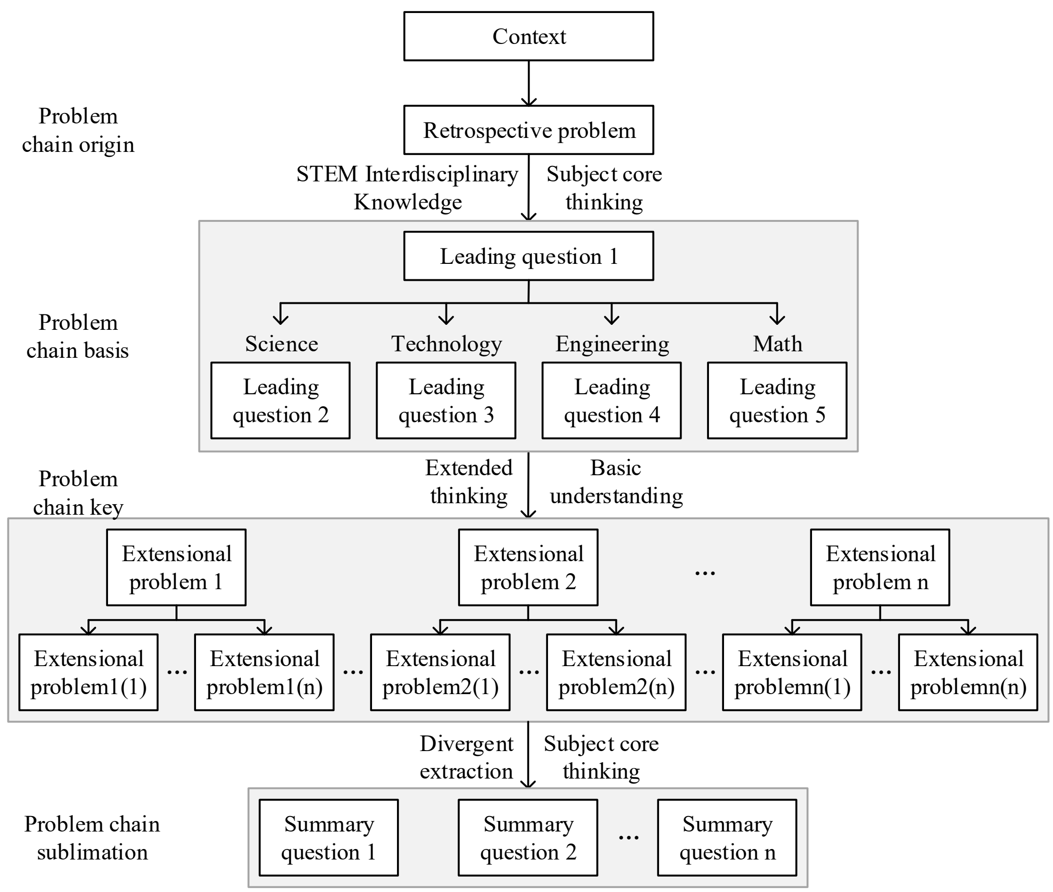

Fig. 2. Problem chain teaching framework for STEM education

2.3. Professional development based on teachers' professional competencies

First of all, the professional capacity building of teachers should be strengthened. Teacher professionalization has become an inevitable requirement for the implementation of STEM education. Specifically, firstly, the entrance of the teacher team should be good. Starting from the entrance is the foundation and prerequisite for improving teachers' professional capacity. Second, do a good job of training in-service teachers. Colleges and universities, relevant educational institutions and companies in different regions can cooperate to offer systematic training programs and courses for the development of STEM teachers' professional competence and provide targeted training for teachers.

Second, strengthen collaboration among teachers of different disciplines. By strengthening collaboration among teachers of different disciplines and forming Professional Learning Communities (PLSs), the lack of teachers' STEM expertise can be remedied. The following points should be noted in specific collaboration:

1) Teachers in the group should reflect the relevance of knowledge among themselves. It is important for teachers to conduct STEM education in such a way that teachers from different disciplines can understand the program topics.

2) Schools make scientific planning so that teachers of different disciplines prepare lessons collectively and collaborate effectively.

3) A good division of labor within the group to clarify the skills and expertise of different teachers.

2.4. Creation of three-dimensional learning environment supported by virtual reality technology

By creating a 3D STEM learning environment, virtual reality technology can bring students a new observation experience, interaction experience and operation experience.

1) Observation experience. Virtual reality technology shifts the teaching content from a two-dimensional plane to a three-dimensional space, bringing students rich sensory cognition and multi-channel learning feedback, a more realistic and natural learning environment, and more three-dimensional resources. The realistic experience can give students a high degree of learning immersion, so that they are completely immersed in the learning atmosphere, thus effectively promoting the development of deep learning.

2) Interactive experience. Deep learning is an inquiry process that integrates knowledge construction and social-emotional communication. The powerful interactivity provided by virtual reality technology can well meet this goal, thus bringing rich interactive experience.

3) Operational experience: The effective implementation of STEM education requires a specialized teaching space for students' practical operation. However, in traditional teaching, the operation experience is limited by objective conditions, such as greater experimental danger, higher cost, insufficient space, lack of instruments and equipment, etc. Virtual reality technology solves the problem well, bringing students a cross-temporal experience, creating realistic space venues and instrumentation, so that students can feel the real situation and get a better practical experience. In the virtual reality environment, students are able to repeat dangerous and costly scientific experiments, thus further improving their hands-on ability.

3. Analysis of motivational factors in STEM education based on DEMATEL-ISM

In order to explore the development path of STEM+ education based on digital visual virtual reality, this paper first combines the DEMATEL method and the ISM method to analyze the factors affecting the development of STEM education, i.e., the motivating factors of STEM education.

3.1. DEMATEL method

DEMATEL, i.e. Decision Laboratory Analysis Method, is a method based on graph theory and matrix tools for the analysis of the importance of system factors, which is able to reveal the important influencing factors and internal structure by analyzing the logical relationship between factors in the system and the direct influence matrix to calculate the factors such as the degree of influence, the degree of being influenced, the degree of cause, and the degree of centrality [25].

Most of the STEM education motivational factors do not exist independently, and there is a certain interaction relationship between two or two factors more or less. Only by further clarifying the interactions between the factors can we analyze the influence mechanism of STEM education development more scientifically and explore the key motivating factors, and the DEMATEL method can realize the above research purposes. The specific calculation process of this method is as follows:

1) Establish a direct impact matrix. The influence relationship between factors is expressed by matrix, and the degree of direct influence of factor x_i on factor x_j is expressed by x_{ij}, and the degree of influence is divided into five different levels: "no impact", "weak impact", "weak impact", "strong impact" and "strong impact" according to the questionnaire score, and it is marked as "0", "1", "2", "3" and "4", so as to obtain a direct impact matrix.

2) Calculate the normalized impact matrix and the integrated impact matrix. Determine the inter-logical relationship between the influencing factors and calculate the normalized impact matrix G and the integrated impact matrix T, where I is the unit matrix of $n \times n$:

$$G = \frac{x_{ij}}{\max_{1 \le i \le n} \sum_{j=1}^{n} x_{ij}} \tag{1}$$

$$T = G(I - G)^{-1} \tag{2}$$

3) Solve for Influence (D_i), Influenced (C_i), Centrality (M_i), and Causality (R_i). Centrality indicates how much of a role the factor plays in the system, and causality indicates how much of an influence the factor has on other factors in the system. If the degree of cause is greater than zero, it is a causal factor, which means that the factor has a greater influence on other factors. If the degree of cause is less than zero, it is a result factor, indicating that the factor is more influenced by other factors.

$$D_i = \sum_{j=1}^{n} x_{ij} (i = 1, 2, \cdots, n) \tag{3}$$

$$C_i = \sum_{j=1}^{n} x_{ji} (i = 1, 2, \cdots, n) \tag{4}$$

$$M_i = D_i + C_i (i = 1, 2, \cdots, n) \tag{5}$$

$$R_i = D_i - C_i (i = 1, 2, \cdots, n) \tag{6}$$

3.2. Interpretive Structural Modeling (ISM)

3.2.1. Working procedures for interpreting structural models. Interpretative Structural Modeling (ISM) is used to analyze the problems related to complex socio-economic systems, decompose the complex system into a number of subsystems (elements), use people's practical experience and knowledge, with the help of computers to construct the system into a multilevel ladder of structural models, this method can be used to turn the ambiguous ideas and views into intuitive, good structural relationships with the model, is particularly suitable for the large number of variables, complex relationship and unclear structure in the system analysis [26]. For this reason, this paper combines the DEMATEL method with the ISM method to analyze the internal relationship between the influencing factors, on the basis of which the hierarchical structural model of the influencing factors of the development of STEM education is established. The main steps of the working procedure of the ISM are shown in Figure 3.

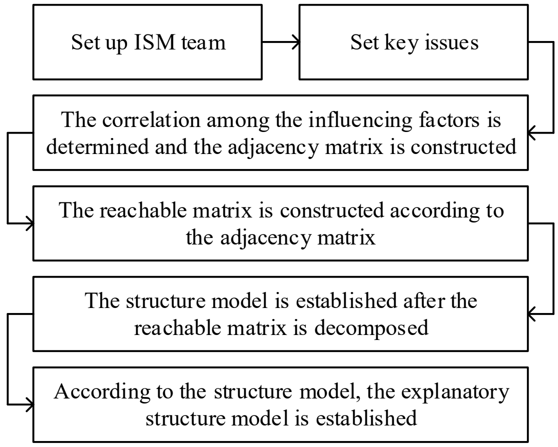

Fig. 3. ISM operating program

3.2.2. Principles and ideas of ISM's division of hierarchies:

1) Directed graphs. ISM expresses one of the simplest system structures by designing directed graphs. The directed graph is composed of nodes and edges, in which each node represents each element of the system, generally using a circle with a symbol to show that the edge represents the relationship between the elements of the system. An example of a directed graph is shown in Figure 4, where the system is composed of three elements, X1, X2, and X3, with the arrows pointing to express: X1 and X2 influence each other, X2 has an influence on X3, and X3 has an influence on X1.

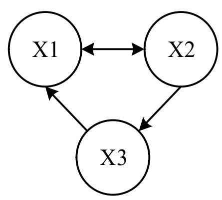

Fig. 4. Example of a directed graph

2) Neighborhood matrix. The adjacency matrix represents a square matrix of relationships between elements. If x_i has some binary influence on x_j, then a_{ij} is 1. If x_i does not have some binary influence on x_j, then a_{ij} is 0. i.e.:

$$a_{ij} = \begin{cases} 1 & \text{If } x_i \text{ has some binary effect on } x_j \\ 0 & \text{If } x_i \text{ doesn't have some binary effect on } x_j \end{cases} \tag{7}$$

Based on the rule in Eq. (7) with the directed graph example of Fig. 4, the corresponding 3rd order square matrix expression is, the

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} \tag{8}$$

3) Reachability matrix. The reachability matrix describes a matrix of transitive binary relationships between different factors via different paths any number of times. The adjacency matrix A and the reachability matrix M are both 0-1 matrices of order n. They also conform to the Boolean matrix algorithm. Passing the adjacency matrix A, it can get the reachability matrix as M, which is calculated as follows:

$$M = (A+I)^r \tag{9}$$

r is the maximum number of passes, and I is the unit matrix with A that the reaction element itself can reach. There is one and only one reachable matrix for the adjacency matrix A in either of the specified arithmetic systems, but there is not only one adjacency matrix result in the realization of the reachable matrix M.

4) Modeling approach. After solving the reachable matrix M, the operational ISM needs to build a model of the recursive order structure, which usually goes through the following steps.

Step1: Establish the reachable set $R(x_i)$ of each influencing factor, $R(x_i)$ is the set of elements that are x_i reachable:

$$R(x_i) = \{x_j \in N \mid M_{ij} = 1\} \tag{10}$$

M_{ij} represents x_i to x_j correlation values, N represents all sets, and $M_{ij} = 1$ represents x_i correlation x_j.

Step2: Establish the prior set $A(x_i)$ of each influencing factor, $A(x_i)$ is the set of elements that can reach x_i:

$$A(x_i) = \{x_j \in N \mid M_{ji} = 1\} \tag{11}$$

Step3: Verify that Eq. (13) holds and that $C(x_i)$ is the set of intersecting factors $R(x_i)$ and $A(x_i)$. If it holds then it states that its corresponding factor x_i is the bottom factor and i rows and i columns are crossed out in matrix M. I.e:

$$C(x_i) = \{x_i \in N \mid R(x_i) \cap A(x_i)\} \tag{12}$$

$$R(x_i) = C(x_i), (i = 1, 2, 3 \ldots, n) \tag{13}$$

Step4: Repeat Step1-3 until all factors are crossed out.

Step5: Create a hierarchy of influencing factors in the order in which they are crossed out.

3.3. *Empirical evidence and analysis*

In order to verify the validity of the DEMATEL-ISM-based influencing factor analysis method and to explore the motivating factors for the development of STEM+ education, this paper conducts empirical research and analysis.

3.3.1. DEMATEL-based power factor analysis. First of all, based on the theory of educational motivation mechanism, this paper constructs the index system of motivation factors for STEM+ education development from three aspects, namely endogenous motivation factors, external motivation factors and synergistic motivation factors, after combining the relevant review literature as well as the opinions of relevant experts and scholars. Among them, endogenous motivational factors are divided into student recognition (X1), social status enhancement (X2), improvement in the quality of student source (X3), teachers' self-worth enhancement (X4), and investment of funds (X5). External motivational factors are divided into economic development (X6), government promotion (X7), market demand (X8), the degree of perfection of STEM+ education system (X9), and industrial restructuring (X10). Synergistic motivational factors are divided into development goal synergy (X11), process synergy (X12), organizational change synergy (X13), information synergy (X14), and resource synergy (X15).

Then, by inviting 30 experts and scholars to score the interrelationships between STEM+ education motivational factors according to a score of 0-4, with a score of 4 indicating an extremely strong influence between the two, a score of 3 indicating a high influence, a score of 2 indicating a moderate influence, a score of 1 indicating a low influence, and a score of 0 indicating that there is no correlation between the two.

Based on the 30 data obtained from the questionnaire survey, the scoring data of 30 experts were averaged and calculated to obtain the initial direct matrix of STEM+ education development motivation factors $X=\left[x_{ij}\right]_{n\times n}$. After summing the rows and columns of the obtained data, the maximum normalization method shown in Equation (1) was taken to obtain the normalized impact matrix G, and then Equation (2) was used to obtain the comprehensive impact matrix of STEM+ education development motivation factors T as shown in Table 1.

Table 1. Composite influence matrix

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
X1	0.08	0.15	0.16	0.10	0.10	0.08	0.08	0.12	0.14	0.11	0.14	0.14	0.13	0.11	0.14
X2	0.15	0.08	0.16	0.14	0.12	0.09	0.11	0.16	0.17	0.16	0.14	0.14	0.13	0.15	0.16
X3	0.12	0.11	0.08	0.14	0.11	0.11	0.07	0.12	0.13	0.11	0.11	0.12	0.14	0.12	0.14
X4	0.16	0.10	0.14	0.09	0.11	0.10	0.13	0.15	0.16	0.15	0.15	0.15	0.14	0.15	0.15
X5	0.09	0.11	0.13	0.11	0.06	0.12	0.08	0.10	0.12	0.13	0.12	0.13	0.15	0.14	0.16
X6	0.09	0.09	0.12	0.10	0.16	0.07	0.11	0.15	0.17	0.14	0.14	0.12	0.12	0.09	0.14
X7	0.19	0.19	0.21	0.20	0.18	0.18	0.10	0.19	0.20	0.18	0.21	0.21	0.21	0.22	0.23
X8	0.17	0.16	0.17	0.12	0.13	0.13	0.14	0.10	0.15	0.15	0.15	0.12	0.17	0.13	0.16
X9	0.10	0.12	0.12	0.11	0.10	0.10	0.07	0.10	0.10	0.10	0.12	0.12	0.12	0.12	0.14
X10	0.07	0.09	0.11	0.10	0.13	0.11	0.06	0.10	0.13	0.06	0.11	0.12	0.11	0.09	0.11
X11	0.13	0.12	0.14	0.17	0.12	0.12	0.09	0.14	0.17	0.15	0.11	0.17	0.17	0.19	0.21
X12	0.15	0.14	0.14	0.11	0.13	0.12	0.11	0.13	0.18	0.11	0.16	0.11	0.13	0.14	0.19
X13	0.16	0.16	0.15	0.14	0.13	0.14	0.11	0.15	0.19	0.17	0.17	0.16	0.11	0.13	0.17
X14	0.13	0.18	0.15	0.13	0.10	0.12	0.11	0.13	0.17	0.14	0.16	0.17	0.20	0.09	0.18
X15	0.11	0.12	0.13	0.12	0.12	0.12	0.11	0.14	0.13	0.09	0.13	0.17	0.13	0.16	0.09

Then, the sum of the rows and columns of the matrix, i.e., the degree of influence (D_i) and the degree of being influenced (C_i), are calculated respectively through the obtained comprehensive influence matrix T. The center degree (M_i) and the cause degree (R_i) of the factors that motivate the development of STEM+ education are obtained by using Equation (5) and Equation (6), respectively, as shown in Table 2. The higher the value of the center degree, the greater its influence on STEM+ education development, and vice versa, the smaller it is. The degree of cause is positive and negative, with positive cause indicating a strong influence on other motivational factors and negative cause indicating a strong influence of the motivational factor by other factors.

In terms of centrality, the mean value of the centrality of synergistic motivational factors, external motivational factors, and endogenous motivational factors is 4.27, 3.89, and 3.79, respectively, which shows that the synergistic motivational factors have the greatest influence on motivational driving of STEM+ education development, followed by the influence of the external environment, and finally the factors of endogenous motivation of the development of each subject. In the dimension of synergistic motivational factors, the most influential is organizational change synergistic factors (4.40), and the least influential is information synergistic factors (4.19). Among the external motivational factors, government promotion (4.38) plays a crucial role, and industrial restructuring (3.45) has the smallest role. In the dimension of endogenous motivational factors, the improvement of social status (3.98) becomes the biggest internal driving force for schools, teachers and students, while the investment of funds (3.55) is more implicit in the promotion of the development of STEM+ education and produces the least driving force.

In terms of the degree of cause, government promotion (1.42) has the highest degree of cause for the development of STEM+ education development and the greatest influence on other factors. In the initial stage of the current implementation of STEM+ education, the top-level design of the government and local education departments plays a key role, so the degree of implementation of government policies and system implementation determines the upper limit of the development of STEM+ education.The degree of reason for the perfection of the STEM+ education system (-0.67) is the smallest, and is vulnerable to the influence of other factors. Therefore, great attention should be paid to the construction and improvement of the educational system in the process of STEM+ education development, and the fundamental factors affecting the development of STEM+ education should be found and controlled.

Table 2. Centrality and causality of the driving factors of STEM+ education development

Variable	D_i	C_i	M_i	R_i
X1	1.78	1.90	3.68	-0.12
X2	2.06	1.92	3.98	0.14
X3	1.73	2.11	3.84	-0.38
X4	2.03	1.88	3.91	0.15
X5	1.75	1.80	3.55	-0.05
X6	1.81	1.71	3.52	0.10
X7	2.90	1.48	4.38	1.42
X8	2.15	1.98	4.13	0.17
X9	1.64	2.31	3.95	-0.67
X10	1.50	1.95	3.45	-0.45
X11	2.20	2.12	4.32	0.08
X12	2.05	2.15	4.20	-0.10
X13	2.24	2.16	4.40	0.08
X14	2.16	2.03	4.19	0.13
X15	1.87	2.37	4.24	-0.50

3.3.2. ISM-based power factor analysis. On the basis of using the DEMATEL method to analyze the cause degree and center degree of STEM+ educational development, this paper further adopts the Interpretive Structural Model (ISM) to explore the hierarchical structure of STEM+ educational development and the overall influencing relationship, which makes the analysis of STEM+ educational development dynamics more systematic and clear.

In order to more intuitively demonstrate the overall division of the STEM+ educational development motivational factor system, a total motivational factor X16 (STEM+ educational development motivational factor) is added. Based on the integrated impact matrix T in the DEMATEL method, the data were converted into a binary relationship by setting an empirical threshold A. The data were converted into a binary relationship by setting an empirical threshold A. Data greater than A is converted to 1 and data less than A is converted to 0. The value of A is finally determined to be 0.168 through expert setting and continuous attempts.Using Boolean operation as a criterion, the reachable matrix M of the STEM+education development motivational factors is obtained by using Equation (9), and then based on the reachable matrix M, the reachable set R (Xi), the precedence set A (Xj), and the common set C (Xi) are obtained as shown in Table 3 shown in Table 3. The reachable set is the set of behavior 1 where the motivational factors are located, the prior set is the set of column 1 where the motivational factors are located, and the common set is the intersection of the reachable set and the prior set.

Table 3. The resulting reachable set, antecedent set and common set

Xi	*R*(Xi)	*A*(Xj)	*C*(Xi)
X1	1,16	1,4	1
X2	2,16	2,4	2
X3	3,16	3,4	3
X4	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	4	4
X5	5,16	4,5	5
X6	6,9,16	4,6	6
X7	7,16	4,7	7
X8	8,16	4,8	8
X9	9,16	4,5,9,11,13,14	9
X10	10,16	4,10	10
X11	8,10,11,12,13,14,16	4,12,13,14	12,13,14
X12	11,15,16	4,11,12,13,14	11
X13	8,10,11,12,13,14,16	4,12,13,14	12,13,14
X14	8,10,11,12,13,14,16	4,12,13,14	12,13,14
X15	15,16	4,12,13,14,15	15
X16	16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	16

Using the $R(Xi) = C(Xi)$ criterion, the first level of STEM+ educational development motivational factors can be obtained as X16, X16 is crossed out from the reachable set, prior set and common set, and then according to the $R(Xi) = C(Xi)$ criterion, the second level of STEM+ educational development motivational factors can be obtained as XI, X2, X3, X5, X7, X8, X9, X10, and X15, and the cycle is carried out according to this method, and finally the STEM+ The multilevel ISM model of educational development motivational factors is shown in Figure 5.

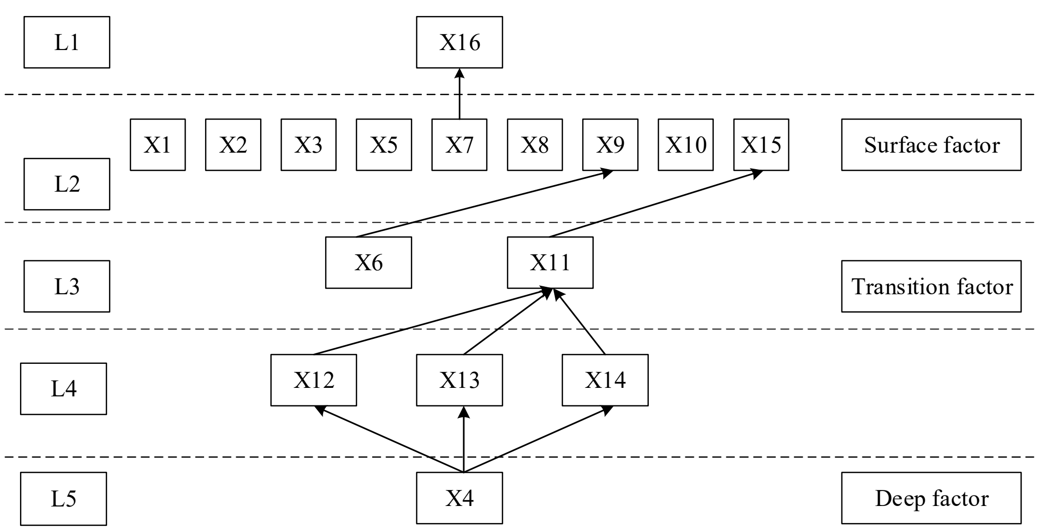

Fig. 5. Multi-level ISM structure for STEM+ education development

4. Group path analysis of STEM+ education development based on QCA

Based on the analysis of the motivating factors of STEM+ education, this paper explores the way of combining paths for STEM+ to achieve high-quality development using the QCA method.

4.1. Qualitative Comparative Analysis (QCA) Methods

Qualitative Comparative Analysis (QCA) method consists of induction and deduction based on set theory from a group perspective to find the causes or combinations of conditions that can influence the outcome variable from the complex structure of multiple cases [27]. QCA method as a meso-level theory has a small to medium-sized sample size of cases, roughly between 10-60, and more than 100 cases if necessary, and there is a balance in the number of cases between cause variables and There is a quantitative balance between the cases, often 10-40 cases selecting 4-7 explanatory conditions, it should be noted that the cases analyzed by this technique are often well known and not anonymous as in the case of micro-large sample questionnaire studies and the selection of the individual variables has to be set based on the theory.

4.1.1. Analytical logic of the QCA methodology. The logical basis of the QCA method is Boolean algebra and set theory. Unlike the linear relationship perspective in regression analysis, the QCA method mainly determines the relationship between the cause variable and the effect variable through the set relationship, and the Boolean algebra operations in mathematics can make this relationship to achieve the most simplified. The logical principle of Boolean minimization is that for any two given expressions, if the results are the same and they differ in only one letter, then that letter can be minimized. The minimized expression, together with the remaining unminimized expression goes to the next round of iterations and the computation is repeated until the end of minimization, so as to find the most compact combination of key causes or conditions that can influence the generation of the result.

The QCA approach measures the results based on two main metrics: consistency and coverage. The consistency of a set Y as a subset of a set X is the proportion of their intersections to the set Y. When the consistency indicator is greater than 0.8, it means that the cause variable is a sufficient condition for the outcome variable, and when the consistency is greater than 0.9, it means that the cause variable is a necessary condition for the outcome variable. The specific arithmetic formula is as follows:

$$\text{Consistency}(X_i \le Y_i) = \sum[\min(X_i, Y_i)] / \sum X_i \tag{14}$$

Where a sufficient condition is whether or to what extent cases with the same antecedent have the same outcome, and a necessary condition is whether or to what extent cases with a particular outcome share the antecedent condition.

After reaching the consistency criterion (e.g., 0.8), the coverage rate can be further calculated, which is used to present the explanatory power of the causal variable for the outcome, if the coverage rate is 0.9, it means that the causal variable or the combination of conditions is able to explain 90% of the sample cases, and the closer the coverage rate is to 1, the more it indicates that the causal variable or the combination of conditions is the only path to reach the outcome variable, and the specific arithmetic formula is as follows:

$$\text{Coverage}(X_i \le Y_i) = \sum[\min(X_i, Y_i)] / \sum Y_i \tag{15}$$

Through the calculation of consistency and coverage indicators, it is possible to determine the explanatory power of different combinations of causal variables or conditions for the results, thus verifying the validity of the conceived influences.

4.1.2. QCA technology. Currently QCA is divided into three main analytical techniques: clear set qualitative comparative analysis, fuzzy set qualitative comparative analysis, and multi-valued set qualitative comparative analysis.

Clear set qualitative comparative analysis (es/QCA) is used to deal with differences in categories and directly dichotomizes the variables 1/0, with a clear correspondence between the outcome and the combination of conditions. However, precisely because the cause and effect variables are dichotomously processed, it is best to prove thresholds based on theoretical knowledge and case experience when cutting, and always be transparent when adjusting thresholds to avoid artificial cutting and splitting of cases with very similar values, and to take the mean or median of the mechanical cutoff point when difficult, or to use more complex such as cluster analysis and other technological methods, but the results cut in this way should be assessed to see if the distribution has a theoretical or practical significance of the distribution.

The fuzzy set qualitative comparative analysis (fs/QCA) accommodates the degree of difference in addition to the category, and introduces the concept of affiliation between 0 and 1. The closer to 1, the higher the affiliation, and the closer to 0, the lower the affiliation, and the threshold between 0 and 1 is not set uniquely, and it can be set as a three-valued fuzzy set, a four-valued fuzzy set, a six-valued fuzzy set, or a continuous fuzzy set (with no equidistant spacing between different levels) by using direct assignment, or using direct calibration to find out the full affiliation threshold, the full non-affiliation threshold, and the intersection threshold. The fuzzy sets can be set as three-valued fuzzy sets, four-valued fuzzy sets, six-valued fuzzy sets, or continuous fuzzy sets (without equidistant intervals between different levels) by direct assignment method, or by direct calibration method, which can find out the thresholds of complete affiliation, complete unaffiliated thresholds, and intersection thresholds, and use the fsqca3.0 calibrate to calibrate original data to the three thresholds of 0.05, 0.5, and 0.95, and the fuzzy sets can be used to connect the quantitative and qualitative measurements due to the setting of thresholds of different levels.

Multi-Valued Set Qualitative Comparative Analysis (mv/QCA) is an extension of Clear Set Qualitative Comparative Analysis and is similar to the treatment of fixed category variables in quantitative analysis, in that it assigns more than just 0 and 1 to a variable, but can be set to multiple numbers, such as 0, 1, and 2. Multi-valued set qualitative comparative analysis is an extension of the QCA method, which can use richer numbers to accomplish a more fine-grained representation of the data representing the order or category, and it can show the category better, thus overcoming the problem of loss of information and contradictory grouping of the clear set to a certain extent. The analysis logic is to convert multiple values into multiple binary numbers, and then use the clear set calculation. Although the multi-valued set can be more detailed representation of the variables, but in practice, do not over-pursuit of fine and have to choose the multi-valued set, because this practice will make the results are not simple enough, the case will tend to be homogenized. There is another application scenario for this analysis method, which is to be used in conjunction with fuzzy set qualitative comparative analysis, which can be used to test the reliability of the results of fuzzy set analysis.

With the development of the methodology and maturity, the analysis software supporting the QCA method is becoming more and more abundant, in addition to the dedicated fs/QCA, TOSMANA, Kirq, acq software, the fuzzy command embedded in the STATA software, the QCA package embedded in the R language, as well as the QCA Add-in for Excel function based on EXCEL can complete the QCA analysis. Combining the characteristics of the three analysis techniques, due to the clear set using the binary division of 0/1, the degree of information loss is large, fuzzy set is more complex than the clear set, not only can indicate the existence or not, but also the degree of the multi-valued set method is currently immature, therefore, this study chooses the fuzzy set analysis method, and the fsqca3.0 software is used for the analysis.

4.2. Experimentation and Analysis

This study uses fsQCA to qualitatively and comparatively analyze the group path of STEM+ education development. fsQCA can effectively deal with the nonlinear relationship between the STEM+ education development system and the level of high quality development, and effectively identify the synergistic and interactive relationship among the conditions, so as to explore the alternative and complementary relationship among the influencing elements. The fsQCA can effectively deal with the non-linear relationship between STEM+ education development system and high quality development level, effectively identify the synergy and interaction between the conditions, and thus explore the substitution and complementary relationship between the influencing elements.

Based on the DPSIR framework, this study takes the level of high-quality development of STEM+ education as the outcome variable, and the five elements of drive, pressure, state, influence and response as the conditional variables, which meets the requirements of the ideal number of group elements (4-7).

4.2.1. Analysis of Requirements. In this paper, fsQCA4.0 was used to analyze the consistency and coverage of 42 cases, and the results of the one-factor requisite analysis obtained are shown in Table 4. In this case, HQDL indicates high-level high-quality development, while -HQDL indicates non-high-level high-quality development.

For high level of high quality development of STEM+ education, the consistency of each conditional variable is greater than 0.6, which can explain the outcome variable as a whole, and according to the high and low coverage rate, the order of the strength of explanation is high response (0.848), high state (0.833), high drive (0.781), high influence (0.704), and high pressure (0.623), which is consistent with the results of existing studies are more consistent, and it also verifies that the condition variables selected in this study are indeed the key variables affecting the development of high quality in STEM+ education.

If the consistency level is greater than 0.9, it means that the condition is necessary for the results. As can be seen in Table 4, the level of consistency of all the variables did not exceed 0.9, and there is not a condition variable as a necessary condition leading to the development of high quality in STEM+ education. This indicates that the high-quality development of STEM+ education is not determined by a single factor, but is affected by the complexity of multiple factors, and it is necessary to analyze the complex causality of its multiple factors concurrently, and to further analyze in depth the group impact of each conditional variable.

Table 4. Necessary condition analysis

Conditional variables and their properties		Result variable			
		HQDL		-HQDL	
Conditional variables	Variable level	Consistency	Coverage rate	Consistency	Coverage rate
DS	High	0.783	0.781	0.463	0.562
PS	High	0.644	0.623	0.611	0.651
SS	High	0.829	0.833	0.441	0.524
IS	High	0.677	0.704	0.397	0.553
RS	High	0.867	0.848	0.404	0.46
-DS	Non-high	0.595	0.482	0.83	0.854
-PS	Non-high	0.685	0.554	0.683	0.683
-SS	Non-high	0.562	0.475	0.877	0.87
-IS	Non-high	0.581	0.474	0.779	0.734
-RS	Non-high	0.466	0.378	0.845	0.874

4.2.2. Analysis of the overall regional conditions grouping. First, taking STEM+ education in region C as the target, the grouping results of high quality development of STEM+ education in the region as a whole are obtained as shown in Table 5. Where "●" indicates the presence of core conditions, "○" indicates the absence of core conditions, "⊙" indicates the presence of auxiliary conditions, "◎" indicates that the auxiliary condition is absent, and "space" indicates that the condition can be present or absent.

As can be seen from Table 5, there are two grouping paths (H1, H2) that can explain the overall high-level high-quality development of STEM+ education in Region C, and three grouping paths (NH1, NH2, NH3) that can explain the non-high-level high-quality development of STEM+ education, reflecting the multiple concurrency and similarity of the high-quality development of regional STEM+ education. In terms of the high-level grouping, the consistency of individual solutions in both groupings exceeds the threshold value of 0.8, indicating that both groupings are sufficient conditions for high-level regional STEM+ education high-quality development. The consistency of the overall solution is greater than 0.9, and the two groupings also constitute a sufficient condition for high-quality development of regional STEM+ education in general. In terms of raw coverage and outcome coverage, the two histomorphisms together explain a large degree of the outcome of high-quality development of regional STEM+ education. In terms of subgroup states, group state H1 suggests that regardless of a region's level of STEM+ education pressures and influences, the combination of drive, state and response as core conditions present can bring about a high level of high-quality development of STEM+ education in the region. Group state H2 shows that even if the pressure factor of a region is a borderline missing state, regardless of the level of the drive factor of the place, under the combination of state, influence and response as a core condition exists, it can bring a high level of high quality development of STEM+ education to the place. In terms of the relationship between the groupings, both groupings contain three core conditions, both include state and response factors, and the main difference lies in the drive and impact factors, which means that there may be a potential substitution relationship between the two.

Overall comparison of the 5 groupings of regional STEM+ education high-quality development (HI, H2, NHI, NH2, NH3) reveals an asymmetry in the antecedent conditions of regional high-level STEM+ education high-quality development and non-high-level high-quality development. Further analysis of the groupings that lead to a non-high level of high-quality development of STEM+ education showed that the consistency of the three non-high-level groupings was greater than 0.9 and the consistency of the results was greater than 0.9, indicating that each of the three groupings (NH1, NH2, and NH3), as well as in general, constitutes a sufficient condition for high-quality development of non-high-level regional STEM+ education. In terms of coverage, the coverage of NH1 is significantly higher than that of NH2 and NH3, indicating that this grouping state is the main cause of non-high levels of high-quality development of STEM+ education.The NHI suggests that regardless of the level of a region's stressors and influences, the level of high-quality development of local STEM+ education is in a non-high state in the absence of the drive, state, and response factors, with drive and Response factors play a central role.NH2 suggests that even if a district's stressors are present as core conditions, the absence of State, Impact & Response may result in a non-high level of high-quality development in STEM+ education, where the Impact & Response factors play a central role. NH3, on the other hand, suggests that even if the state factor exists as a core condition and the drive, pressure & impact factors exist as marginal conditions in a region, it may bring about a non-high level of high-quality development of STEM+ education in the absence of the response factor as a core condition. The above three non-high-level group state paths fully reflect the impact of the absence of response factors on the high-quality development of regional STEM+ education.

Table 5. Overall configuration results

Conditional variables	HQDL		-HQDL		
Solution	H1	H2	NH1	NH2	NH3
DS	●		○		⊙
PS		◎		●	⊙
SS	●	●	◎	◎	●
IS		●		○	⊙
RS	●	●	○	○	○
Consistency	0.991	0.918	1.000	0.972	0.969
Original coverage	0.642	0.364	0.675	0.430	0.194
Unique coverage	0.314	0.043	0.281	0.044	0.015
Result consistency	0.961		0.982		
Result coverage	0.679		0.743		

4.2.3. Comparative Analysis of Eastern, Central and Western Conditional Groupings. The calibration and conditional grouping analysis of the variables were conducted in the eastern, central and western regions of Region C, respectively, and six grouping paths of STEM+ education high-quality development at high levels in the three regions were obtained as shown in Table 6. Among them, “E”, “M” and “W” represent the eastern, central and western regions, respectively.

Comparing EHI and EH2, it can be seen that regardless of the level of drive and pressure factors in the STEM+ education development system of the eastern region, when the state, impact and response factors exist as the core conditions, it can bring a higher level of high-quality development of STEM+ education in the eastern region, and therefore, this study summarizes the driving path of high-quality development of STEM+ education in the eastern region as follows This study summarizes the driving path of high-quality development of STEM+ education in the eastern region as the “state-impact-response” trinity driving type.

There are two configuration pathways for the high-quality development of STEM+ education in the central region: the "state-response-impact" driving path (MH1) in the absence of "stress", and the all-round development driving path (MH2) with "state-response" as the core. Both pathways use state and response factors as core conditions.MH1 shows that regardless of the level of the driving factors in the central region, even in the absence of stressors as marginal conditions, relying on higher levels of state, impact and response factors can bring about higher levels of high-quality development of STEM+ education in the region, with state and response factors playing a central role.MH2 on the other hand shows that when the five dimensions are more balanced, playing the central role of state and response factors can bring a higher level of high quality development of STEM+ education to the central region.

There are two configuration paths for the high-quality development of STEM+ education in the western region: the "state-response" support path (WH1) in the absence of "drive-pressure", and the fourfold driving path (WH2) with "state" as the core in the absence of "influence". Where WHI shows that regardless of the level of the influence factor, even under the influence of the absence of the drive and stress factors as core conditions, supported by the state and response factors as core conditions, it is able to bring about a higher level of high quality development of STEM+ education in the area.WH2 shows that for the areas where the state factor is present as core conditions, even under the absence of the influence factor as a core condition accompanied with the Drive, Pressure and Response factors as the support of the presence of marginal conditions can also bring about a higher level of high quality development of STEM+ education.

Table 6. Comparative analysis of eastern, central and western conditional configurations

Conditional variables	HQDL					
Solution	EH1	EH2	MH1	MH2	WH1	WH2
DS	◎	⊙		⊙	○	⊙
PS	◎	⊙	◎	⊙	○	⊙
SS	●	●	●	●	●	●
IS	●	●	⊙	⊙		○
RS	●	●	●	●	●	⊙
Consistency	0.904	0.997	1.000	1.000	0.923	0.991
Original coverage	0.425	0.442	0.439	0.416	0.458	0.251
Unique coverage	0.118	0.134	0.343	0.343	0.302	0.089
Result consistency	0.921		1.000		0.935	
Result coverage	0.553		0.746		0.554	

Comparing the grouping paths of high-quality development of STEM+ education in Region C and its eastern, central, and western regions, it can be seen that all eight grouping paths take the state and response factor as the core condition, which indicates that the high-quality development of regional STEM+ education can not be separated from the support of the state and response factor, indicating that the equipping of human, material, and financial resources, the state of the local teaching of STEM+ education, as well as the government's attention to STEM+ education are all important prerequisites for a regional STEM+ education high-quality development. STEM+ education are important prerequisites for the high-quality development of STEM+ education in a region. With better overall advantages in the development of STEM+ education, the eastern and central regions are more balanced and synergistic than the western region, and the influence factors of the eastern and central regions play a more important role in the high-quality development of STEM+ education than those of the western region. In contrast, although the antecedents of the western region have not achieved balanced and coordinated development, they can still rely on the core conditions to play a role in realizing a higher level of high-quality development of STEM+ education.

5. Conclusion

In this paper, we successfully realized the design of STEM+ education development path based on digital visual virtual reality, and analyzed the dynamic mechanism of STEM+ education development based on DEMATEL-ISM method, and explored the group path of STEM+ education high-quality development using QCA method.

First, the DEMATEL method is used to find the center degree and cause degree. The mean value of the centrality degree of synergistic motivational factors, external motivational factors, and endogenous motivational factors is 4.27, 3.89, and 3.79, respectively, indicating that synergistic motivational factors have the greatest influence on motivational drive of STEM+ education development, followed by the influence of the external environment, and finally the factors of endogenous motivation of the development of each subject. In the dimension of synergistic motivational factors, the most and least influential are organizational change synergistic factors (4.40) and information synergistic factors (4.19), respectively. Among the external motivational factors, government promotion (4.38) is the most important. And in the dimension of endogenous motivational factors, the improvement of social status (3.98) is the biggest internal drive for the development of STEM+ education. Meanwhile, government promotion (1.42) has the highest degree of reason for the development of STEM+ education development. It indicates that the degree of execution of government policy and system implementation plays a key role in the current implementation of STEM+ education. And the degree of reason for the perfection of the education system (-0.67) is the smallest, which is susceptible to the influence of other factors. Therefore, in the process of STEM+ education development, the construction and improvement of the education system should be highly emphasized. In addition, a multilevel ISM model of motivational factors for STEM+ education development was constructed.

Secondly, this paper uses the fuzzy set qualitative comparative analysis (fs/QCA) method to analyze the grouping paths of the high quality development of STEM+ education in region C. The results show that there are two high-level grouping paths and three non-high-level grouping paths. The results show that there are two high-level grouping paths and three non-high-level grouping paths, and the grouping paths in the east, center and west are different, but the high-quality development of STEM+ education can not be separated from the support of the state factor and response factor. Therefore, it is necessary to improve the mechanism and institutional construction to provide guarantee for the development of STEM+ education, and at the same time, formulate the development strategy according to local conditions, drive the high-quality development of STEM+ education by synergistic paths, and focus on the regional priorities, and lead the high-quality development of STEM+ education in the region by the key development.

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