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Research on the Design Path of Interdisciplinary Teaching Aids for STEAM Project-based Learning in the Context of Science Education Based on Optimization Theory

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Abstract STEAM enables students to learn knowledge, apply knowledge, transfer knowledge and improve ability in the process of playing, and teaching aids become the most direct and explicit carrier of "playing", which is an important tool for the implementation of teaching activities. In this regard, this paper designs STEAM teaching aids for science education and analyzes the effect of teaching aids based on the cognitive diagnostic model (CDM). By constructing cognitive attributes and their hierarchical relationships, developing and improving cognitive diagnostic test papers based on the Q_c matrix theory, and diagnosing and analyzing the mastery of cognitive attributes of science education at the overall and individual levels based on students' responses. After the quiz, 46.15% of the students basically mastered the knowledge points of science education with the help of STEAM teaching aids, and the remaining 53.85% of the students had deficiencies in mastering at least one of the cognitive attributes of science education. Based on the above analysis, it is convenient for teachers to carry out remedial teaching and personalized counseling, so as to improve the teaching effect of science education.

Index Terms STEAM teaching aids, cognitive diagnostic model, cognitive attributes, popular science education

I. Introduction

In 2016, China's Ministry of Education pointed out the need to strengthen the application of information technology curriculum in interdisciplinary learning (STEAM education), and to cultivate students' information awareness, creativity and interdisciplinary thinking through STEAM (i.e., science, technology, engineering, arts and mathematics) education. Since the promulgation of the document, STEAM education has developed rapidly, for example, Hangzhou, Wuhan, Chengdu, and Beijing have opened courses covering STEAM in schools, involving 3D printing, robotics, laser cutting, and 3D design, etc., and Chengdu and other places have trained a group of STEAM teachers [1]-[5]. STEAM education, as a novel educational method for training future well-rounded talents, has been increasingly favored by people in the education sector. Fundamentally, the goal of STEAM education aims at solving real-world problems, which can motivate students to apply professional knowledge and technological means of various disciplines to cope with problems encountered in life, which undoubtedly helps to stimulate students' interest in learning as well as their creative thinking and innovative consciousness, and to improve their active exploration, practical operation, and interdisciplinary abilities [6]-[9]. Effective basic science education helps to cross disciplinary boundaries, encourages students to synthesize knowledge from multiple disciplines, and strengthens students' practical inquiry and problem-solving skills.

The project-based learning approach centered around problem solving is currently the main way of implementing STEAM activity courses internationally [10]. The case design and practical activities shown in the appendix of the new standard reflect the concept of interdisciplinary project-based learning, but the number of cases is relatively small. Project-based learning is an educational approach that puts students at the center of a real-life scenario through open inquiry in small groups to learn the core concepts and principles of a discipline in depth, and in this way improves students' innovative thinking and practical skills [11]. Project-based learning and interdisciplinary integration are closely linked, and project-based learning perfectly fits the educational concept of science education, which is an important way to implement interdisciplinary integration of science education [12].

Popularization of science education is a very important educational activity in modern society, and its purpose is to improve the scientific literacy and scientific cognition of the general public by disseminating scientific knowledge to the public. In popular science education, more and more cutting-edge science and technology, emerging disciplines have been widely introduced and publicized, such as artificial intelligence, biotechnology, space exploration, etc., and these emerging fields of scientific knowledge make popular science education more attractive and more able to satisfy the public's desire for scientific knowledge [13]-[15]. While popular science education is an important battleground for STEAM education, the design of its teaching aids suffers from unremarkable interaction effects, single presentation of science, poor self-integration of students between different sciences, and waste of resources due to the disposable characteristics of most teaching aids [16]-[19]. Therefore, it is important to design teaching aids that meet the numerous needs of contemporary interdisciplinary integration, significant practical interaction effects, and sustainability. Optimization theory lies in finding an optimal solution for the system under study that reasonably utilizes human, material and financial resources, brings into play and improves the effectiveness and efficiency of the system, and ultimately achieves the optimal goal of the system [20]. With the increasing progress of science and technology and the development of production and management, optimization method has become an important theoretical basis and indispensable method of modern management science, and plays an increasingly important role in various fields such as education management.

The study designed STEAM project-based learning interdisciplinary aids for science education and analyzed students' knowledge acquisition based on a cognitive diagnostic model. Firstly, the cognitive attributes and their hierarchical relationships for data analysis were identified, based on which the test Q matrix for this study was determined. Then, the reliability, validity, and differentiation of the test paper were analyzed through the pretest and formal test to verify the rationality of the attribute hierarchical relationship and the feasibility of the test paper. Finally, the probability of subjects' cognitive attribute mastery was derived based on the seq-GDINA model, the gender difference was analyzed, and the attribute mastery pattern of the subjects was estimated by this method.

II. Theoretical foundations

II. A. STEAM teaching aids

STEAM education is an interdisciplinary and innovative teaching method integrating five disciplines of science, technology, engineering, mathematics and art. The curriculum advocates the integration of disciplinary knowledge for teaching in the form of projects or problems, in which students are placed in real problem situations, strengthen their memory and understanding of knowledge through the process of discovering problems, exploring problems, cooperating and communicating, and solving problems, and actively constructing their own knowledge systems. STEAM competence is gradually formed [21]. As the name suggests, STEAM teaching aids are teaching tools that assist the smooth implementation of STEAM teaching, and they are an important carrier for realizing students' “learning by doing” and “thinking by playing”, and providing students with a good teaching experience.

At present, China's STEAM education products are mainly occupied by “programming” and “robotics”, and both educators and education designers believe that information technology is STEAM education, and there are deviations in their understanding of STEAM education. To implement the interdisciplinary teaching of STEAM education, to change the unitary nature of traditional education, and to realize the integration of multiple disciplines, the objectives of STEAM teaching, teaching content and teaching aids must break through the current inertia of thinking that STEAM education needs to be high-end and technological.

II. B. STEAM teaching aid design process

II. B. 1) Construction of a graded teaching system

The construction of the STEAM graded teaching system based on the optimization theory is a process of reverse design based on the STEAM education concept, with the whole teaching process based on the competence objectives that meet the cognitive level of students. The so-called reverse design refers to taking the STEAM competence that students should have at this stage as the starting point, analyzing the knowledge system that needs to be mastered in order to obtain the competence, and using project-based learning as a hand to carry out teaching practice. This paper proposes the construction of STEAM graded teaching system with innovation ability as the core goal and other abilities involved.

Innovative ability refers to the ability of an individual to comprehensively utilize mastered knowledge and learning materials to produce some kind of novel, unique, socially or personally valuable ideas, opinions, methods and products, and consists of three elements: innovative consciousness, innovative thinking and innovative skills. Analyzed from the perspective of constructivism, the acquisition of students' ability is the process of constructing their own knowledge system independently and applying migration to solve practical problems. Both low-order and high-order abilities are developed in the process of learning knowledge in various subject areas, and knowledge is the basis for the development of ability. Therefore, the cultivation of creative ability needs to be built on the basis of disciplinary knowledge and skills, follow the cognitive level of students at all levels, and be deeply integrated into the whole process of construction and teaching of the five major disciplines of science, engineering, technology, arts and mathematics. With the method of applying the knowledge and skills of the disciplines, with the aim of creatively solving the realistic problems of increasing difficulty, combining theory and practice, from shallow to deep, from simple to complex, from low to high, and constantly discovering problems, analyzing problems, solving problems, and practicing innovations through the project practice, the innovative ability of students is gradually cultivated. Accordingly, STEAM teaching with innovation ability as the core goal orientation should also reflect this hierarchical progression, which can be divided into a number of step-by-step incremental sub-objectives, with the previous sub-objective being the basis for the next sub-objective to be reached, and each sub-objective corresponds to a certain cultivation level in the teaching system, and project design is carried out according to the characteristics of the students at this level. With reference to the above criteria for the division of the progression path and the thinking logic of Piaget's theory of the stages of students' cognitive development, this paper divides the innovative ability into three levels: knowledge comprehension and simple application ability, reasoning and analyzing and scientific inquiry ability, and transfer and innovative practice ability. Combined with the theory of constructivism, it establishes a STEAM hierarchical teaching system with innovation ability as the core orientation and other abilities involved.

II. B. 2) Instructional Aids Design Process under STEAM Graded Instructional System

Based on the interdisciplinary teaching aids design under the STEAM graded teaching system, following the STEAM graded teaching model, the teaching aids ability, knowledge and projects are combined to promote the smooth implementation of STEAM teaching and to cultivate the ability to meet the interdisciplinary necessities. This paper argues that the design of teaching aids is oriented to the competencies that students should cultivate, and the way to combine real projects and problems, using existing knowledge and teaching aids to complete the project or solve the problem. According to the cognitive level of students, determine the competence to be cultivated at each stage, deconstruct and reorganize the competence to form a knowledge system, design projects based on the concept of interdisciplinary, design supporting teaching aids according to the needs of the project, and finally determine the results of students' competence cultivation through a diversified evaluation method, so that the teaching aids and the competence, knowledge, projects and evaluation form a complete organic system.

Ability refers to the ability that students should have after STEAM teaching, including innovation ability, problem solving ability, 21st century skills and China's core literacy and other ability indicators, this study specifically refers to the cultivation goal oriented by innovation ability and other abilities are involved. Knowledge is the bridge connecting the competence and the program, and it is the foundation of all competence acquisition. According to the STEAM competency objectives, based on the concept of hierarchical teaching, the competency objectives of each level are deconstructed and reorganized, and a new knowledge system is established by combining the curriculum standards. Knowledge at this time includes knowledge and skills of various disciplines and life experiences related to the completion of the project, and the degree of difficulty of the knowledge is based on the competency indicators and the cognitive level of students to ensure the rationality and effectiveness of teaching. Project is a teaching method for knowledge learning and ability development, the project in this process is based on subject knowledge and real projects developed in real life, each level of competency objectives consists of multiple projects, and a project consists of multiple activity sessions. Teaching aids are designed according to the activity needs of a project to assist in the smooth running of the project and to bring a comfortable and interesting teaching experience to the students.

III. Science education assessment methodology

Cognition is the process of acquiring knowledge or using knowledge, which is the most basic psychological process of human beings. Diagnosis is the process of using various techniques, methods and tools to gain a comprehensive and in-depth understanding of an object and to give a detailed analytical report based on the evaluation [22]. According to the scope of use, it can be divided into cognitive diagnosis in the broad and narrow sense. Cognitive diagnosis in the broad sense refers to: the construction of relationships between quantitative scores that can be externalized and internal cognitive characteristics of the subject. Cognitive diagnosis in the narrow sense refers to the diagnosis and categorization of subjects according to whether they have mastered the traits or skills measured by the test in the field of education and teaching, so as to help teachers to teach and students to learn.

Cognitive Diagnostic Model (CDM) is a mathematical statistical model that incorporates cognitive variables and evaluates an individual's cognitive situation by reflecting the process of constructing cognitive activities within the individual based on the subject's performance on the test items [23]. It reveals the cognitive characteristics and strategies of individuals in problem solving and decision making, and understands the strengths, deficiencies, and potential cognitive deficits of their cognitive processes in order to better understand and intervene in cognitive behaviors. The DINA statistical model is a common diagnostic model with a high degree of discriminative accuracy, and it has been widely studied. With the continuous improvement and optimization of the DI-NA model, simulation and empirical studies of the seq-GDINA model based on multilevel scoring have shown better results, overcoming the limitations of 0-1 scoring and defining an attribute-definition method based on item categories, which fully exploits the information of multilevel scoring items. In this paper, we will explore the effect of STEAM project-based learning interdisciplinary aids on science education based on the cognitive diagnostic model (CDM).

III. A. The seq-GDINA model

The seq-GDINA model is known as a sequential process model, which is a Q matrix defined separately from the item level and the score category level, which focuses on the relevant attributes involved in the problem solving process [24]. Typically, the item-level Q matrix defines the measurement Q matrix for the question as $q_j = (111)$, whereas the score-category-based Q matrix needs to be calibrated for each step (category) of the question, and the Q matrix for the arithmetic question can be calibrated as $q_j = \begin{pmatrix} 100 \\ 010 \\ 001 \end{pmatrix}$, done in three steps, where "1" means that the corresponding property is mastered. In contrast, the Q -matrix based on the scoring categories provides more insight into the students' problem solving thinking, thus improving the accuracy of the subjects' classification results. The principle is as follows:

For a subject whose attribute mastery pattern is α_c, the probability of correctly answering in category h on item j is $S_j(h \mid \alpha_c)$. Then:

$$S_j(h \mid \alpha_c) = \begin{cases} 1, h = 0 \\ 0, h = H_j + 1 \end{cases} \tag{1}$$

where H_j is the category sum of topic j, the probability that the subject scores h on item j is:

$$p\left(X_j = h \mid \alpha_c\right) = \left[1 - S_j\left(h+1 \mid \alpha_c\right)\right] \prod\nolimits_{x=0}^{h} S_j\left(x \mid \alpha_c\right) \tag{2}$$

The sum of the probabilities of scoring various scores on item j for each mastery pattern is then 1 for each subject:

$$\sum\nolimits_{h=0}^{H_j} p\left(X_j = h \mid \alpha_c\right) = 1 \quad \forall c \tag{3}$$

The number of attributes measured in each category on item j affects the probability that a subject will score on that topic. For example, in a test with K attributes, set K_j^* to be the number of attributes measured on topic j and K_{jh}^* to be the number of attributes measured on item j category h. $L = 2^{K_{jh}^*}$ is all simplified mastery patterns, and α_{ljh}^* denotes the l th mastery pattern. For the mastery pattern α_{ljh}^*, the probability function of its h category on item j is denoted as:

$$\begin{aligned} S_j(h \mid \alpha_{ljh}^*) &= \phi_{jh0} + \sum_{k=1}^{K_{jh}^*} \phi_{jhk} \alpha_{lk} \\ &+ \sum\nolimits_{k=k+1}^{K_{jh}^*} \sum\nolimits_{k=1}^{K_{jh}^*-1} \phi'_{jhhkk} \alpha_{lk} \alpha'_{lk} + \cdots + \phi_{jh12\cdots K_{jh}^*} \prod\nolimits_{k=1}^{K_{jh}^*} \alpha_{lk} \end{aligned} \tag{4}$$

III. B. Basic process of cognitive diagnosis

Cognitive diagnosis generally follows the following steps:

In the first step, based on the actual teaching needs, the subject knowledge or ability to be diagnosed is split, and each part is defined as a cognitive attribute.

In the second step, a cognitive analysis is conducted based on the target content to determine a logical hierarchical relationship of attributes, and at the same time, an appropriate cognitive diagnostic measurement model is selected.

The third step is to develop a cognitive diagnostic test paper based on the initially established attribute hierarchy.

In the fourth step, the rationality of the attributes and their hierarchical relationships is validated using some technical means. If the validation fails, it is necessary to go back to the second step.

In the fifth step, the cognitive diagnostic test paper is distributed on a wide scale and the study is formally launched.

Step 6, the collected data are coded and analyzed to organize the cognitive diagnostic results.

Step 7, based on the diagnostic results, targeted remedial measures are developed.

III. C. Q -matrix and Q_c -matrix

Currently, most CDMs are constructed on the basis of Q -matrix theory, which in the usual case consists of a 0-1 matrix with J (number of test items) rows and K (number of attributes) columns. If item j measures attribute k, $Q_{jk}=1$. If item j does not measure attribute k, then $Q_{jk}=0$. The Q -matrix needs to satisfy two basic principles: the Q -matrix should contain a reachability matrix R reflecting the relationships of the cognitive attributes to each other. Each attribute of the Q matrix should be measured no less than three times. The attribute definition method improves the traditional Q matrix into a Q_c matrix to allow modeling of cognitive processes for different categories of the same item. The Q_c matrix requires items to be answered sequentially, and in building the Q_c matrix, the Q matrix is still defined in the same way for questions that are scored in a two-level format (e.g., single-choice, fill-in-the-blanks), and for questions that are answered in a multilevel scoring format the steps necessary for the answer are first determined, and then scored according to the steps necessary for the subjects to successfully complete the question while answering. If question j has H_j consecutive necessary steps to solve the question, then the ordered categories of its answer results from category 0 to H_j total H_j+1. The use of the Q_c matrix allows access to more detailed information about subjects across response categories, providing a fresh perspective on the development of cognitive diagnostic models for multilevel scoring.

IV. Experimental design of cognitive diagnostics for science education

IV. A. Identify cognitive attributes and construct hierarchical relationships

Cognitive attributes refer to the knowledge and skills, etc. required to complete the quiz. On the premise of reading the literature and in-depth analysis, six first-line textbook teachers who teach advanced mathematics were invited to analyze and discuss the six cognitive attributes finally identified as shown in Table 1. It contains foundational cognition, interdisciplinary integration, dynamism and timeliness, critical thinking development, systematic thinking construction, and practice orientation.

Table 1: Cognitive properties and coding

Cognitive attribute	Coding
Fundamental cognition	A1
Interdisciplinary integration	A2
Dynamics and timeliness	A3
Critical thinking culture	A4
Systematic thinking building	A5
Practical guide	A6

The inter-attribute hierarchy is a specific description of the connection between the extracted cognitive attributes, and the cognitive attributes are extracted from the core concepts, and there may be a mental order, a logical order, or a hierarchical relationship between the attributes, which is called the inter-attribute hierarchy. In this study, a preliminary hierarchical structure was developed by an expert panel, and the rationality of the hierarchical structure was verified by using the “oral report method”, in which the students' thinking processes were demonstrated by their oral answers to the questions.

Table 2: Ideal mode

Serial number	A1	A2	A3	A4	A5	A6
1	0	0	0	0	0	0
2	1	0	0	0	0	0
3	1	1	0	0	0	0
4	1	1	1	0	0	0
5	1	1	1	1	0	0
6	1	1	1	1	1	0
7	1	1	1	1	0	1
8	1	1	1	1	1	1

IV. B. Defining the ideal mastery model

The quiz contains 6 cognitive attributes, then there are a total of 24 possible mastery patterns that subjects may produce, but not all of them conform to the cognitive laws of definite knowledge, where the mastery pattern that conforms to the formulated hierarchical relationship between the attributes is called the ideal mastery pattern. It is a 0-1 matrix where 0 represents not mastering the attribute and 1 represents mastering the attribute. The ideal mastery patterns of cognitive attributes calculated according to the expansion algorithm are shown in Table 2.

IV. C. Building the Q_c matrix

In order to avoid students guessing the answers to the questions as much as possible, there were no multiple-choice questions in the test questions, so the pretest questions included fill-in-the-blanks questions with 0-1 scoring, as well as short-answer and proof questions with multiple levels of scoring and the cognitive attributes of definite integrals contained in this Q_c matrix were all examined and examined at least three times. The Q_c matrix of the developed pretest paper, based on the principles and techniques of test preparation, is shown in Table 3.

Table 3: The Q_c matrix of the definite integral and its application

	Item	Cat	A1	A2	A3	A4	A5	A6
1	1	1	1	0	0	0	0	0
2	2	1	1	1	0	0	0	0
3	3	1	1	1	0	0	0	0
4	4	1	1	1	1	0	0	0
5	5	1	1	1	1	1	0	0
6	6	1	1	1	1	1	1	0
7	7	1	1	1	0	0	0	0
8	7	2	0	0	1	1	0	0
9	8	1	1	1	1	1	0	0
10	8	2	0	0	0	0	1	0
11	9	1	1	1	1	1	0	0
12	9	2	0	0	0	0	0	1
13	10	1	1	1	1	1	0	0
14	10	2	0	0	0	0	0	1
15	10	3	0	0	0	0	0	0
16	11	1	1	1	1	1	0	0
17	11	2	0	0	0	0	1	0
18	11	3	0	0	0	0	0	0

IV. D. Implementation of pre-testing

Sixty-five students from a major 1 class in school A were used as subjects for a uniform test after the students learned science based on STEAM aids. There were 17 questions with a total score of 25 points, and the quiz lasted 90 minutes, and finally 65 valid answer sheets were recovered with a recovery rate of 100%.

Currently, cognitive diagnostic research on the reliability of the questions focuses on 3 aspects, which are CTT-based reliability, attribute retesting consistency index and categorical consistency reliability index. The CTT-based Cronbach's reliability is 0.7052, indicating that the overall reliability level of the test paper is acceptable to a certain extent, and the categorization accuracy and consistency indexes are 0.7386 and 0.8257, respectively, indicating that the test reliability is high. The mean value of the attribute retesting consistency index is 0.9892. It indicates that the method has a high level of reliability, and the reliability of each attribute reaches more than 90%.

Combining the 3 approaches, the reliability of this test is relatively satisfactory. The two indicators of guessing parameter g and missing parameter s can also be used to determine the reliability and validity of the test. When both g and s are not higher than 0.4, the reliability and validity meet the standard. The guessing parameter g reflects the probability of a student guessing correctly, thus adjusting for questions with low ability but guessed correctly with a high probability, while the missing parameter s allows for modification of questions with a high probability of missing. The g and s parameters for each question were derived from the pretest answer data and the Q_c matrix, which showed that the miss parameters for all items were within the standard range, while the guessing parameters for items 4, 7, and 17 were higher than the standard values at 0.96, 0.53, and 0.66, respectively, indicating that most of the test questions were reliable and valid. The analysis of the question differentiation revealed that only question 4 had a differentiation not exceeding 0.20. The parameter estimation, combined with the question differentiation, led to the final elimination of test question 4, and the modification of questions 7 and 17 under the group discussion, which resulted in the finalization of the official quiz paper.

V. Official tests

V. A. Descriptive statistical analysis

The data obtained was first statistically analyzed and the detailed information is shown in Table 4. It can be concluded that the experimental test paper was scored out of 24 and out of the 65 students tested, the lowest score was 5, the highest score was 24 and the average score was 15.36. Except for questions 13-16, the plurality of the remaining 12 questions is the full score of this question. Multi-level scoring questions are more students can get a part of the score because they are given points by steps, but it is more difficult to get the full score. The first three questions have mean scores above 0.8, and most students performed well on these questions. Questions 4-5, 7-9, and 11 have mean scores between 0.6 and 0.8, indicating that more than half of the subjects performed well on these test items. Questions 6, and 10, on the other hand, had mean scores below 0.6, both of which examined critical thinking development (A4), which is more complex than the other questions, and therefore had lower mean scores.

Table 4: Descriptive statistical analysis

	Full mark	Mode number	Min	Max	Mean	SD
Item1	1	1	0	1	0.83	0.37
Item2	1	1	0	1	0.84	0.382
Item3	1	1	0	1	0.87	0.387
Item4	1	1	0	1	0.62	0.471
Item5	1	1	0	1	0.66	0.482
Item6	1	1	0	1	0.54	0.482
Item7	1	1	0	1	0.77	0.474
Item8	1	1	0	1	0.62	0.471
Item9	1	1	0	1	0.75	0.469
Item10	1	1	0	1	0.53	0.499
Item11	1	1	0	1	0.75	0.436
Item12	2	2	0	2	1.23	0.817
Item13	3	2	0	3	1.97	0.881
Item14	2	1	0	2	1.13	0.721
Item15	3	2	0	3	1.76	0.816
Item16	3	2	0	3	1.66	0.904
Total score	24	13	5	24	15.36	4.053

The statistics of the total score of all subjects are shown in Figure 1. The largest number of subjects with a total score of 14 was 35, and there were also many subjects with 12, and 16 points. From the overall point of view, the total score of this test is low, and the average total score is near the passing line.

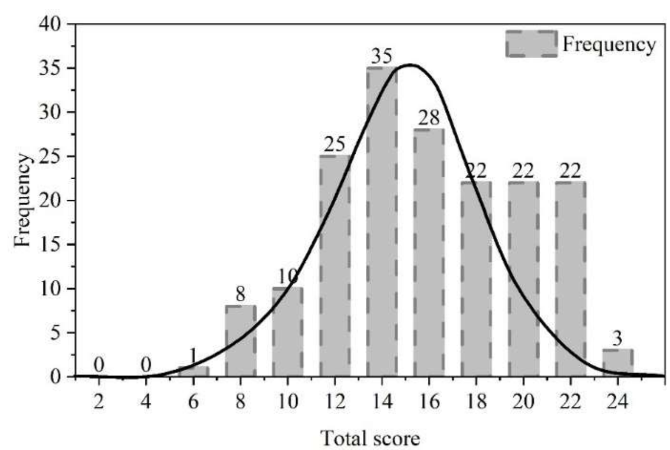

Figure 1: The total score of the subjects

The scores of subjects of different genders were analyzed, as shown in Table 5. It can be seen that the number of girls is greater than that of boys among the students who scored more than 20 points, and the number of boys is

3 more than the number of girls in the high scoring range of 18-24 points, which is not a big difference, and in general, the scores of both sexes are basically more than 10 points, and there is not a big difference between the number of boys and girls in the remaining ranges except for the number of girls who are significantly higher than that of boys in the range of 20-22 points.

Table 5: Different gender subjects were analyzed

	Male(32)		Female(33)	
Score interval	Frequency	Percentage	Frequency	Percentage
0-2	0	0.00%	0	0.00%
2-4	0	0.00%	0	0.00%
4-6	0	0.00%	1	3.03%
6-8	3	9.38%	5	15.15%
8-10	5	15.63%	5	15.15%
10-12	13	40.63%	12	36.36%
12-14	17	53.13%	18	54.55%
14-16	16	50.00%	12	36.36%
16-18	13	40.63%	9	27.27%
18-20	15	46.88%	7	21.21%
20-22	9	28.13%	13	39.39%
22-24	1	3.13%	2	6.06%

Comparison of male and female scores is shown in Figure 2. The box line plot shows that the male and female scores are about the same, indicating that there is no significant difference between the scores of male and female students on this quiz.

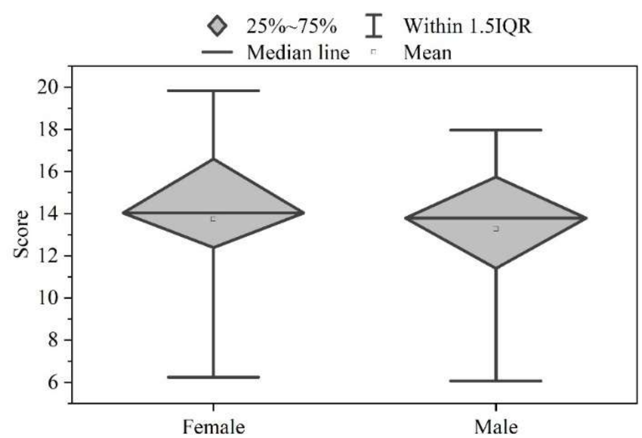

Figure 2: The list of male and female

V. B. Cognitive diagnostic analysis based on the Seq-GDINA model

The test paper of this study examined six cognitive attributes of science education and each cognitive attribute was examined at least three times. In this chapter, the cognitive diagnostic platform will be utilized to analyze the cognitive diagnostic analysis of the test data of 65 students.

V. B. 1) Cognitive Attribute Mastery Probability Analysis

Cognitive diagnosis utilizes the number of correct answers to questions examining a cognitive attribute to assess a student's mastery of a cognitive attribute. The more questions a student answers correctly, the greater the probability that he or she has mastered a cognitive attribute. The average probability of mastery of each cognitive attribute for all students in science education is shown in Figure 3. Students had the highest probability of mastering A2 Interdisciplinary Integration at 0.869, followed by A1 Foundational Knowledge (0.793), A3 Dynamism and Timeliness (0.669), A4 Critical Thinking Cultivation (0.636), and A5 Systematic Thinking Constructs (0.586), and had the lowest probability of mastering A6 Practice Orientation at 0.426. This indicates that students have a relatively good mastery of the science education's foundational knowledge relatively well, while the attribute of practice orientation requires students to be able to flexibly apply what they have learned to practice, which is more demanding, so students have a poorer grasp of the A6 attribute.

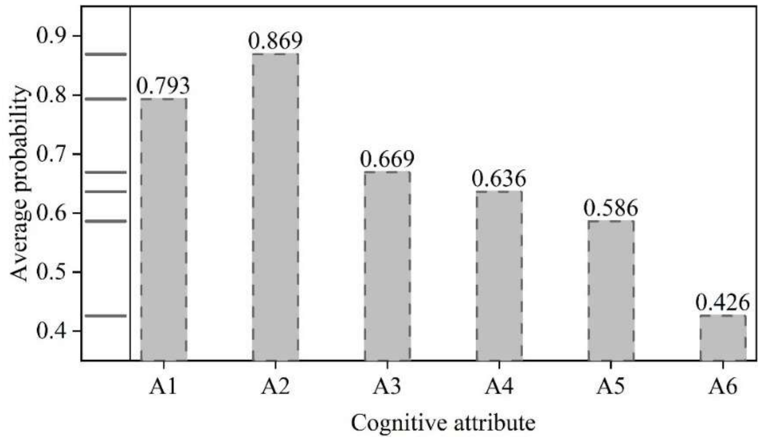

Figure 3: Science education cognitive properties

V. B. 2) Attribute mastery model categorization and probability analysis

(1) Categorization of students' attribute mastery patterns

Cognitive diagnostic analysis of all students' data using the Seq-GDINA model can be calculated to obtain students' cognitive attribute mastery patterns on science education. Three parameter estimation methods, namely, great likelihood estimation (MLE), great a posteriori estimation (MAP), and Bayesian expectation a posteriori estimation (EAP), are usually used to obtain the identification of three types of students' mastery patterns, namely, MLE mastery pattern, MAP mastery pattern, and EAP mastery pattern, respectively. In this paper, subjects' mastery of cognitive attributes is categorized into mastery group, pending group and non-mastery group. It is stipulated that the probability of mastery of an attribute for subjects categorized into the mastery group is greater than 0.6, and the corresponding attribute mastery pattern is recorded as 1. Subjects categorized into the non-mastery group with the probability of mastery of an attribute less than 0.4 are categorized into the non-mastery group, and the corresponding attribute mastery pattern is recorded as 0. The probability of mastery of an attribute for subjects categorized into the pending group ranges between 0.4-0.6, and the corresponding attribute mastery pattern depends on the specific circumstances. According to the three different algorithms each student can be categorized into one attribute mastery mode, and some of the students' attribute mastery mode categorization data are shown in Table 6. According to the data in the table, it can be seen that there are differences in the attribute mastery patterns of students estimated by different algorithms, and not all students can reach the ideal mastery level, and the attribute mastery patterns of some students can not be categorized in the ideal mastery patterns.

Table 6: Some student attributes master pattern classification

Student number	Response mode	Attribute master mode		
		MAP	MLE	EAP
1	1100110101221013	111000	111000	111000
2	1111111111002003	111000	111000	111000
3	1111110100211003	111000	11100	111100
4	1101110011211203	111110	101110	111110
5	1111111111212012	111111	110111	111111
6	1110111110200000	111111	111110	111111
7	1001110111201000	100000	100001	100000
8	1111111111212012	111111	111011	111111
9	1110111110200000	110000	110010	110000
10	1001110111201000	10000	10010	10000

In fact, when the cognitive attribute hierarchy is reasonably defined, the mastery patterns of most students can be categorized into ideal mastery patterns. Therefore, we categorized the attribute mastery patterns estimated by 65 students based on the three algorithms of MAP, MLE, and EAP into the nine ideal mastery patterns calculated in the previous section, and then selected the best algorithm by calculating the imputation rate under each algorithm. The comparison of student mastery pattern imputation rates is shown in Table 7. The cognitive diagnostic results of all students rooted in the Seq-GDINA model had the highest imputation rate under the EAP algorithm, which was 75.38%, and subsequent studies will be conducted to analyze the cognitive diagnostic results of students under the EAP algorithm.

Table 7: The students master the comparison of the pattern

Ideal mode	MAP	MLE	EAP
000000	2	1	1
100000	4	1	4
110000	9	3	6
101000	0	0	0
110100	1	1	1
111110	4	2	2
111111	5	8	30
111000	6	2	3
111100	2	1	2
In total	33	19	49
Classification rate	50.77%	29.23%	75.38%

(2) Analysis of the probability of students' attribute mastery pattern categorization

The number and percentage of students in the nine ideal mastery modes under the EAP mastery model are shown in Table 8. 49 students were categorized in the eight ideal mastery modes, and no students were categorized in the attribute mastery mode of 101000. Among them, the largest number of students, 46.15%, were categorized under the mastery pattern of 111111, which indicates that students have mastered all the cognitive attributes of science education, i.e., 46.15% of the students basically mastered the knowledge points of science education and were able to correctly answer each of the related questions, while the remaining 53.85% of the students had deficiencies in the mastery of at least one of the cognitive attributes of science education. Secondly, the number of students categorized as 110000 and 100000 mastery mode is relatively large, accounting for 9.23% and 6.15% respectively. These students have mastered the A1 attribute, i.e., they have mastered the basic concepts of popularization of science education, but their mastery of the subsequent knowledge of popularization of science education is deficient, which makes them unable to solve problems flexibly in the application of popularization of science education, so they need to strengthen the corresponding practice. Students categorized in the 111110 mastery mode accounted for 3.08% of the total number of students, this part of the students do not master the A6 attribute, but have a good mastery of other attributes, teachers can strengthen this part of the students for the comprehensive application of science education practice, so that students master the A6 attribute, the attribute mastery mode into 111111. Of all the subjects, only one student (1.54%) was categorized in the 000000 mastery mode, which is a small number but needs to be brought to the attention of teachers.

Table 8: The EAP master mode falls into the probability of the population

Serial number	Ideal mode	Number	Percentage
1	000000	1	1.54%
2	100000	4	6.15%
3	110000	6	9.23%
4	101000	0	0.00%
5	110100	1	1.54%
6	111110	2	3.08%
7	111111	30	46.15%
8	111000	3	4.62%
9	111100	2	3.08%

In summary, the STEAM project-based learning interdisciplinary aids designed in this paper can facilitate science education to a degree that ensures that nearly half of the population fully grasps all of the cognitive attributes of science education.

VI. Conclusion

Based on the cognitive level, this study identifies the abilities that need to be cultivated, deconstructs and reorganizes the abilities to form a knowledge system, based on the interdisciplinary concept, the deconstructed and reorganized knowledge points are designed into a project, and the supporting teaching aids are designed according to the needs of the project. Taking 65 students of a major class 1 in school A as the formal test subjects, we started from various aspects and conducted cognitive diagnostic research on the probability of cognitive attribute mastery and attribute mastery patterns in science education using the seq-GDINA model, and came up with the following conclusions:

(1) Students' total scores and cognitive attribute mastery probabilities were first calculated as a whole, and students' attribute mastery patterns were categorized. The students' scores were then analyzed by gender, and there was not much difference between the scores of male and female students.

(2) Attribute mastery pattern estimation methods adopted The EAP method has a high categorization rate and the estimation method is appropriate. A total of 49 people were categorized into the ideal attribute mastery model, accounting for 75.38% of the total number of students

(3) Nearly half of the students completely mastered all the cognitive attributes of science education. Teachers can target teaching according to the diagnostic results to further improve the teaching effect of science education.

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