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A Study on the Design Path of Interdisciplinary Teaching Aids for STEAM Project-Based Learning in the Context of Science Education Based on Multi-Objective Planning

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ABSTRACT

Based on the scheme of multi-objective planning, this paper conducts an in-depth investigation on the design path of interdisciplinary teaching aids for STEAM project-based learning in the context of science education. A multi-objective planning model is constructed, which includes the integration of subject knowledge, the cultivation of students' ability and cost control, and a multi-objective genetic algorithm is introduced to solve the model. The feasibility of the design path of this paper and the enhancement of students in project-based learning are verified through real cases. Compared with the other three schemes, the interdisciplinary teaching aids production using the mathematics and electricity fusion scheme can maximize the Pareto optimality, i.e., the integration of disciplinary knowledge and the cultivation of students' abilities are maximized, as well as the goal of minimizing the production cost. The use of this paper's scheme to produce teaching aids and apply them in course practice can effectively enhance students' interest in learning and course performance.

Keywords: multi-objective planning; multi-objective genetic algorithm; Pareto optimization; teaching aids design

1. Introduction

Science teaching is based on experiments, demonstration experiments are an essential part of the teacher's class, and good demonstration aids can improve the teacher's teaching effect and make students understand the knowledge points better [1-2]. In teaching practice, relying only on textbooks, videos, etc., sometimes it is difficult to speak well and clearly teaching the key points, and students are also difficult to understand. At this time, teaching aids can be used to assist teaching, so that students can learn and master new knowledge [3-6]. Teaching aids are sometimes designed to make up for the

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experimental effects that cannot be achieved in reality, or to visualize microscopic phenomena, and they can also be used to design experimental teaching aids through interdisciplinary fusion to make the experimental phenomena more visualized and concrete [7-9].

As a comprehensive education model, STEAM education aims to develop students' creativity and ability to discover and solve problems. However, learning burnout is an important factor affecting the quality of students' learning. Therefore, how to design STEAM teaching aids to alleviate students' learning burnout and enhance students' learning interest and learning quality has become a topic of discussion among many scholars [10-13]. At present, many scholars carry out research on teaching aids from the psychological and physiological levels of students. Due to the diversity of student interaction with teaching aids, the reasons affecting students' experience and learning needs are more complicated [14-15], and the general methods of weighting are difficult to ensure objectivity, which makes the design of teaching aids detached from the real needs of users, whereas Structural Equation Modeling (SEM) is good at measuring the variables that can't be measured in practice, such as motivation, attitude, psychology and so on. For example, motivation, attitude, psychology and other issues can be measured by indirect indicators, SEM can analyze the complex relationship between multiple dependent and independent variables [16-17].

This paper highlights the necessity of interdisciplinary teaching aids production through the introduction of STEAM education concept and project-based learning. Based on the analysis of the design objectives and constraints in interdisciplinary teaching aids production, a multi-objective planning model is constructed, which contains three objectives: the degree of integration of disciplinary knowledge, the effect of students' ability cultivation and the cost, as well as the constraints of syllabus and curriculum standards, safety constraints and technical feasibility constraints. The multi-objective genetic algorithm is used to code and evaluate the adaptability of the teaching aids design scheme to realize the solution of the multi-objective planning model. The multi-objective planning model is used to solve different interdisciplinary teaching aids design solutions and compare and select the optimal solution set that can realize the design objectives of this paper under the constraints. According to the results of the model solution, the interdisciplinary teaching aids are designed in practice, and the designed teaching aids are applied to actual teaching, and the students' interests and achievements are compared and analyzed before and after the use of the teaching aids in this paper, so as to verify that the interdisciplinary teaching aids designed with the multi-objective planning model in this paper play an important role in the STEAM project-based teaching.

2. Theoretical foundations

2.1. STEAM Education Philosophy

STEAM education is the integration of five fields: science, technology, engineering, art and math [18]. Unlike traditional subject-specific teaching, STEAM emphasizes interdisciplinary integration with the aim of cultivating students' innovative thinking and comprehensive quality. In STEAM education, science plays the role of exploring the unknown, helping students build curiosity about the natural world and encouraging them to explore and understand the world around them through observation, experimentation, and data analysis. Technology, on the other hand, provides students with the tools and platforms to effectively access, analyze and share information. Engineering education, on the other hand, combines theoretical knowledge with real-world applications and develops problem-solving skills that enable students to design, create, and optimize various systems and structures. Compared to these three, art plays a unique role in STEAM. It is not only designed to cultivate students' aesthetics and creativity, but more importantly, it can help students see problems from different perspectives and develop their diversified ways of thinking. In STEAM education, the arts are not isolated from other disciplines, but are closely integrated with them so that students can experience the arts while exploring science and technology. Math is the cornerstone of STEAM. It provides the precise language and tools for the other four domains, helping students to think logically, analyze quantitatively, and abstract complex problems. In STEAM education, math is no longer about single calculations and formulas, but is integrated with real-world problems and situations so that students can experience the usefulness and importance of math in practice.

Finally, STEAM education emphasizes interdisciplinary integration rather than the depth of a single field. It encourages students to look at problems from multiple perspectives and develop their creative and critical thinking skills. And this kind of education undoubtedly provides students with a comprehensive, practical and creative learning environment, enabling them to better adapt to the challenges of the future.

2.2. Project-based learning

Project-based learning is a student-centered teaching method [19], in which students experience the process of problem formulation, program design, project implementation and outcome evaluation by completing a specific project, in which they take the initiative to acquire knowledge, enhance their skills and cultivate their attitudes. Project-based learning is characterized by authenticity, comprehensiveness, inquiry and cooperation, which can effectively promote students' deep learning and the development of higher-order thinking skills.

2.3. Multi-objective planning

Multi-objective planning is a branch of mathematical planning, which studies how to optimize multiple objective functions simultaneously under certain constraints [20]. In the design of teaching aids, multiple objective functions can include maximization of teaching effectiveness, minimization of cost, improvement of student satisfaction, and so on. Through the multi-objective planning method, a set of non-inferior solutions can be found, i.e., solutions that cannot further improve any of the objectives without worsening the other objectives, and then a satisfactory solution can be selected from them according to the decision maker's preference.

3. Interdisciplinary teaching aid design analysis

3.1. Analysis of design objectives

1) Subject knowledge integration objectives. Ensure that the teaching aids can cover the knowledge condolences of multiple disciplines, and organically combine the concepts and principles of different disciplines to help students establish an interdisciplinary knowledge system. For example, when designing a teaching aid with the theme of environmental protection, it is necessary to integrate the knowledge of biology, chemistry, engineering and other disciplines, so that students can understand the ecosystem, the chemical principles of pollution control and the engineering design of environmental protection facilities.

2) Objectives of students' ability development. Focus on cultivating students' critical thinking, innovation, teamwork and problem-solving abilities. Through the use of teaching aids, students are guided to think and explore on their own initiative, encouraged to come up with innovative solutions, and cooperate with their peers to complete tasks in the project-based learning process, improving their comprehensive competence literacy.

3) Cost Control Objectives. Under the premise of guaranteeing the quality and educational effect of teaching aids, the design, production and use costs of teaching aids are reduced as much as possible in order to improve their generalizability and popularity. This includes the cost of raw materials, processing costs, labor costs and post maintenance costs and other considerations.

3.2. Constraints

1) Syllabus and curriculum standards and constraints. The design of teaching aids must be in line with the corresponding syllabus and course standards, to ensure that the knowledge and skills covered are closely related to the teaching content, and can effectively assist the development of teaching activities.

2) Safety constraints. Teaching aids must ensure the personal safety of students in the process of use, avoiding the existence of sharp edges and corners, toxic and hazardous substances, easy to damage and lead to danger and other safety hazards. The selection of materials and structural design should be subject to strict safety testing and evaluation.

3) Technical feasibility constraints. Considering the current level of technology and production process, the design scheme of teaching aids should be practically operable and able to be produced and realized using existing technical means and resources. Avoid overly complex designs or reliance on immature technologies to ensure that the teaching aids can be produced and put into use on time and with high quality.

4. Interdisciplinary Teaching Aid Design Modeling and Solving

4.1. Multi-objective planning model

Multi-objective planning, often noted as MOP, refers to mathematical models and methods for the optimal design of a system or process in the presence of multiple conflicting objectives. It is centered on optimizing multiple objectives at the same time, rather than simply optimizing one objective. Multi-objective planning can be applied to a variety of real-world problems where the objective is to maximize or minimize multiple objective functions to satisfy different requirements and constraints. In this case, trade-offs and balances are required to find a set of optimal solutions or a set of effective solutions that result in optimal coordination and balance among these objectives.

In real life, when there are multiple conflicting and contradictory objectives that need to be optimized at the same time, obtaining the optimal solution often requires seeking a compromise and balance between the objectives, which is defined as a multi-objective optimization problem, in which the traditional methods are difficult to effectively deal with and solve such problems.

The process of establishing a mathematical model based on the multi-objective problem is shown below, and the specific expression is:

$$minf(x) = (f_1(x), f_2(x), \cdots, f_m(x))^T \tag{1}$$

$$s.t \begin{cases} g_i(x) \le 0, i = 1, 2, \cdots, p \\ h_r(x) = 0, r = 1, 2, \cdots q \end{cases} \tag{2}$$

$$x = (x_1, x_2, \cdots, x_n)^T \tag{3}$$

If there is some $x = (x_1, x_2, \cdots, x_n)^T$ that satisfies all the required constraints, then $x = (x_1, x_2, \cdots, x_n)^T$ is a feasible solution to this multi-objective problem.

In most cases, the solution to a multi-objective problem is not unique, but rather a set of multiple solutions. Each solution is independent of the other, and there is no situation where one solution is better than the others. As a result, contradictions and paradoxes usually arise when solving multi-objective problems. Therefore, it is essentially impossible to obtain an optimal solution for each objective simultaneously. The ultimate goal of this study is to realize the optimality of the solutions so that each objective reaches a relatively optimal situation.

4.2. Modeling

4.2.1. Establishment of the objective function:

1) Degree of discipline knowledge integration function. Let the number of disciplines for which the teaching aids are designed be n, and for each discipline $i(i=1,2,\cdots,n)$, use x_{ij} to denote the degree to which the jth knowledge point of the discipline i is represented in the teaching aids $0 \le x_{ij} \le 1$, and w_{ij} to denote the importance weight of the knowledge point in the discipline i. Then the degree of knowledge integration function $F_1(x)$ of the disciplines can be expressed as:

$$F1(x) = \sum_{i=1}^{n} \sum_{j=1}^{m_i} w_{ij} x_{ij} \tag{4}$$

Where m_i is the number of knowledge points embodied in the teaching aids for subject i.

2) The effect function of students' ability cultivation. Students' critical thinking ability, innovation ability, teamwork ability and problem solving ability are labeled as C, I, T and P respectively, and their cultivation effect can be quantified by certain evaluation indexes and methods, which are set as y_C, y_I, y_T and y_P. Since these competencies are interrelated and have different importance, introducing weights a, b, c, and $d(a+b+c+d=1)$, the student competency development effect function $F_2(y)$ can be expressed as:

$$F_2(y) = ay_C + by_I + cy_T + dy_P \tag{5}$$

3) Cost function. Let the design cost of the teaching aids be C_d, the production cost be C_p, and the usage cost be C_u. The total cost function $F_3(C)$ is:

$$F_3(C) = C_d + C_p + C_u \tag{6}$$

4.2.2. Mathematical expression of constraints:

1) Syllabus and curriculum standard constraints. For the knowledge points of each discipline, there is a corresponding minimum knowledge coverage requirement x_{ij}^L set according to the requirements of the syllabus and course standards:

$$x_{ij} \ge x_{ij}^L, i=1,2,\cdots,n. j=1,2,\cdots,m_i \tag{7}$$

2) Safety constraints. Introduce safety index S, set safety threshold S^T by evaluating the material safety and structural stability of the teaching aids, and require $S \ge S^T$. Specific evaluation indexes and calculation methods can be determined according to relevant safety standards and norms.

3) Technical feasibility constraints. According to the existing technical level and production process, set the feasible range for the design parameters and production process parameters of the teaching aids. For example, if the dimensional accuracy of a component of a teaching aid is p, the permissible error range is set to $[p^L, p^U]$, i.e. $p^L \le p \le p^U$.

4.2.3. Multi-objective planning models. Synthesizing the above objective functions and constraints, the interdisciplinary teaching aid design model based on multi-objective planning is established as follows:

$$\begin{cases} maxF_1(x) = \sum_{i=1}^{n}\sum_{j=1}^{m_i} w_{ij}x_{ij} \\ maxF_2(y) = ay_C + by_I + cy_T + dy_P \\ minF_3(C) = C_d + C_p + C_u \\ s.t. x_{ij} \ge x_{ij}^L, i = 1,2,\cdots,n. j = 1,2,\cdots,m_i \\ S \ge S^T \\ p^L \le p \le p^U \end{cases} \tag{8}$$

4.3. Model solving

4.3.1. Multi-objective genetic algorithms. Multi-objective Genetic Algorithm (MOGA) is an intelligent optimization algorithm based on the mechanism of natural selection and genetic variation, which is suitable for solving multi-objective optimization problems. By simulating the process of biological evolution, he performs selection, crossover and mutation operations on the individuals in the population (i.e., the coded representation of the teaching aids design solution), and iteratively evolves, so that the population gradually approximates to the optimal solution set of Pareto (Pareto). In each generation, the fitness of an individual is calculated based on the value of its objective function, and individuals with high fitness have a higher probability of being selected for genetic manipulation, thus gradually optimizing each objective.

4.3.2. Algorithmic steps:

1) Coding and initializing populations. A suitable coding method is used to encode the teaching aid design scheme, such as binary coding or real number coding, to represent the design parameters as chromosomes. Randomly generate an initial population, with each individual representing a possible teaching aid design scheme, while determining algorithmic parameters such as population size, crossover probability, and mutation probability.

2) Adaptation evaluation. For each individual in the population, its fitness value is calculated according to the established objective functions $F_1(x)$, $F_2(y)$ and $F_3(C)$. Since it is a multi-objective optimization problem, methods such as non-dominated sorting, congestion distance, etc. are used to determine the fitness of individuals to distinguish the degree of superiority or inferiority of different individuals in each objective.

3) Selection operation. Based on the fitness value of individuals, tournament selection, roulette wheel selection and other methods are used to select individuals of the parent generation from the population for genetic manipulation. The principle of selection is to prioritize individuals with high fitness, so that excellent design solutions have more chances to be passed on to the next generation.

4) Crossover operation. Crossover operation is performed on the selected parent individuals according to a certain crossover probability to generate new offspring individuals. Crossover operation simulates the process of gene exchange in biological inheritance, by exchanging part of the chromosome segments of the two parent individuals to generate offspring individuals with new characteristics, so as to explore the space for new design solutions.

5) Mutation operation. Mutational manipulation of the chromosomes of offspring individuals with a certain probability of mutation, randomly changing the values of certain genes. Mutation operation helps to increase the diversity of the population, avoiding the algorithm from falling into the local optimal solution too early, and possibly discovering better design solutions for teaching aids.

6) Updating the population. Combine the individuals of the parent generation with the individuals of the offspring generation, perform non-dominated sorting and elite retention strategy according to the fitness value, select the population of the new generation, eliminate the individuals with low fitness, and keep the size of the population unchanged.

7) Termination condition judgment. Set the maximum number of iterations or the optimal solution of the population for a number of consecutive generations without significant improvement as the termination conditions of the algorithm. When the termination conditions are met, the algorithm stops iterating and outputs the Pareto optimal solution set, from which the decision maker can select the most suitable teaching aids design according to the actual needs.

5. Case Studies

5.1. Multi-objective planning for the design of teaching aids

Parallel plate capacitors are a major challenge in teaching high school physics and are also a test point on the college entrance exam. How to design a parallel plate capacitor that contains the integration of knowledge from multiple disciplines is intuitively important in high school physics STEAM science project learning. This section mainly explores the optimal design path of parallel plate capacitors using the multi-objective planning model constructed in the previous section.

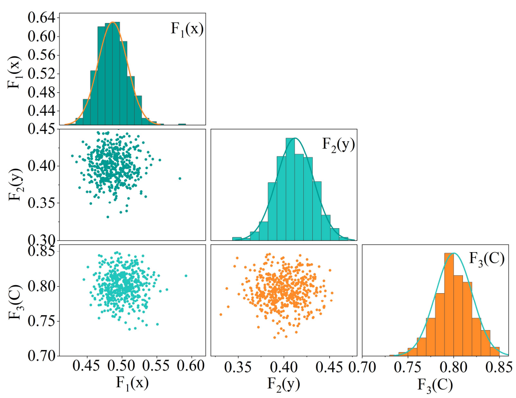
5.1.1. Model Parameterization and Solving:

1) Determination of objective function weights. By means of expert consultation and questionnaire survey, the three objective weights of the degree of discipline knowledge integration, the effect of students' ability cultivation and cost control are determined to be 0.4, 0.4 and 0.2 respectively.

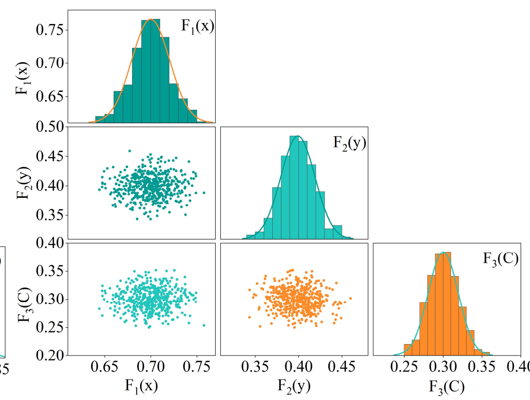
2) Setting constraint parameters. According to the syllabus and curriculum standards of the secondary school physics discipline, the minimum coverage requirements of knowledge points such as the definitional and deterministic calculations of capacitors, and the influencing factors of the capacitance of parallel plate capacitors are determined. In terms of safety, considering that the teaching aids may be operated by students, thresholds such as electrical safety indicators and structural strength safety indicators are set. Meanwhile, according to the existing processing equipment and technical conditions of the school, the technical feasibility constraints such as dimensional accuracy and material selection range for the production of the teaching aids were determined.

3) Solving using MOGA. The above multi-objective genetic algorithm is used to solve the design model, and a set of Pareto optimal solution sets are obtained after several iterations, each solution represents a feasible teaching aid design scheme, which has different performance in the three objectives of subject knowledge integration, student ability cultivation and cost control.

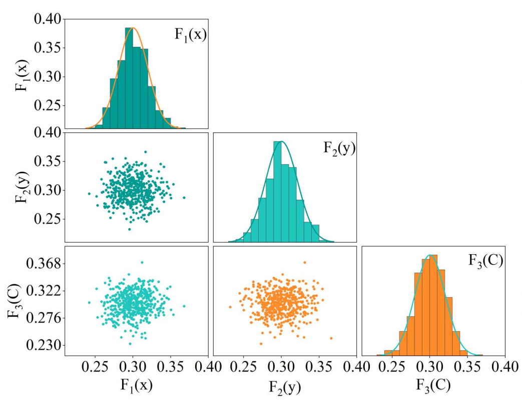
5.1.2. Analysis of results and program selection. The experiments use the multi-objective planning model constructed in this paper to generate four different design schemes for parallel plate capacitors, which are the fusion scheme of mechanics and electricity (Scheme 1), the fusion scheme of optics and electricity (Scheme 2), the fusion scheme of thermology and electricity (Scheme 3), and the fusion scheme of mathematics and electricity (Scheme 4), and Fig. 1 shows the trade-offs between the objective functions under the different teaching aids design schemes, and (a)- (d) represent the experimental results of Schemes 1-4, respectively. From the figure, it can be seen that the relationship between the three objective functions of the degree of integration of subject knowledge, the effect of students' ability development and the cost under the four scenarios varies. The values of the degree of integration of subject knowledge ($F_1(x)$) and the effect of students' ability development ($F_2(y)$) are lower in Scheme 1, while the value of the cost function ($F_3(C)$) is larger. This result is completely contrary to the goal of interdisciplinary teaching aids design in this paper, and therefore Scheme 1 cannot be used as the optimal solution set. In Scheme 2, the degree of integration of subject knowledge ($F_1(x)$) is relatively large and the cost function ($F_3(C)$) is relatively small, but the effect of students' ability development ($F_2(y)$) is also low, so Scheme 2 is also not an optimal solution. Similarly, in Program 3, although the cost function ($F_3(C)$) is smaller, the degree of integration of subject knowledge ($F_1(x)$) and the effect of student ability development ($F_2(y)$) is also smaller, using this program for interdisciplinary teaching aids design is only knowledge to achieve the goal of minimizing the cost of interdisciplinary knowledge integration, student ability development of the two main objectives of the design of teaching aids have not been achieved, so Program 3 can not be used as the design of this paper as well as the optimal program for the design of teaching aids. Therefore, Option 3 is also not the optimal program for the design of teaching aids in this paper. Compared with the other three options, the value of the integration of subject knowledge ($F_1(x)$) and the effect of students' ability cultivation ($F_2(y)$) in Option 4 is larger, while the value of the cost function ($F_3(C)$) is smaller, which effectively realizes the objective function of multi-objective planning, so Option 4 can be chosen as the optimal option for the design of interdisciplinary teaching aids in this paper.



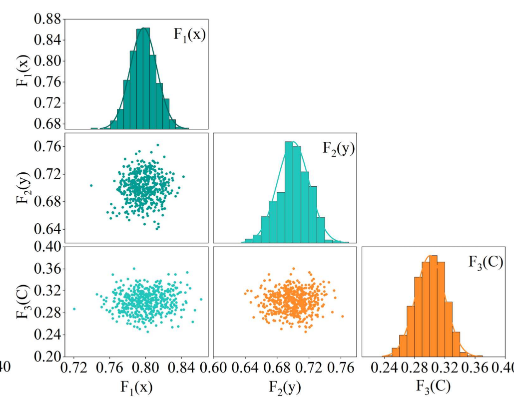
(a) Solution 1



(b) Solution 2



(c) Solution 3



(d) Solution 4

Fig. 1. Multi-objective planning results

Figure 2 shows the multi-objective planning solution results of Scheme 4, from which it can be clearly seen that the value of subject knowledge integration ($F_1(x)$) of the parallel plate capacitor teaching aids designed using the math and electricity integration scheme is in the range of 0.70 to 0.88, the value of students' ability cultivation ($F_2(y)$) is in the range of 0.60 to 0.80, while the cost ($F_3(C)$) is in the range of 0.24 to 0.36. Considering the actual teaching needs, resource situation and economic conditions of the school, Scheme 4 significantly achieves the Pareto optimality of maximizing the integration of subject knowledge, maximizing the development of students' ability and minimizing the cost. This scheme guarantees a better control of the cost under the premise of a certain degree of subject knowledge integration and the effect of students' ability cultivation, which further indicates that it is possible to use this scheme as an optimal solution set for the design of interdisciplinary teaching aids.

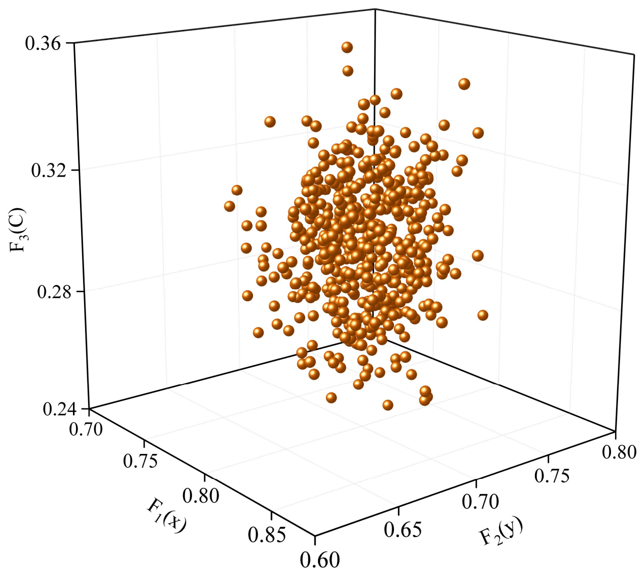


Fig. 2. Solution result

5.2. Production of interdisciplinary teaching aids

Based on this paper, according to the multi-objective planning model to solve the interdisciplinary teaching aids production of the optimal program, with plastic slide, metal plate, capacitance table and other materials homemade “parallel plate capacitor demonstrator”, can directly quantitatively explore the factors affecting the capacitance of parallel plate capacitors, to solve the problem of the students' erroneous concept of the former, so that the students intuitively and clearly Observe the experimental phenomenon, have a basis for guessing the factors affecting the capacitance, and logically deduce the capacitance of the decision formula.

5.2.1. Experimental setup and its construction:

1) Production materials. Made of parallel rail, frame body, metal plate, capacitance meter (model: A6013L), copper, aluminum plate (20cm×20cm×2mm), plastic rail, plastic pulley, PVC foam board, plexiglass plate (20cm×20cm×2mm), cardboard (20cm×20cm×2mm).

2) Production method:

(1) Cut the PVC foam board into two 45×30cm specifications as the upper and lower base plate, and then use the PVC foam board to make three 30cm×5cm specifications of the bracket, and mark the position of the guide rail on the base plate with a pencil.

(2) Cut the plastic guide rails into six 40cm long, and then stick them on the pre-set position of the base plate with hot melt glue.

(3) Fix the pulleys with hot melt glue on the four corners of the copper and aluminum plates, and keep the four metal plates at the same height, and measure this height with a scale.

(4) In order to put the metal plate into the guide, adjust the fixed height, so that the metal plate can move freely, and then the previously made bracket is fixed to the three outer edges of the main body,

as far as possible not to block the side of the metal plate.

(5) Print out the scale on A4 paper, cut it to fit and stick it next to the base plate rail. Cut out the red arrow from cardboard and stick it to the metal plate so that the red arrow is aligned as parallel as possible to the metal plate.

5.2.2. Exploring the relationship between the components of the teaching aids:

1) How to use teaching aids. The determinant of a flat plate capacitor is $C = \frac{\varepsilon s}{4\pi kd}$. It can be seen that the capacitance of a parallel plate capacitor is related to the distance between the plates of the pole plates, the positive area, and the material of the dielectric, so the capacitance of a parallel plate capacitor can be changed by changing these 3 quantities.

2) Relationship between the parallel plate capacitor and the distance between the plates. Keep the aluminum plate is facing the area of 400cm^2 so that the aluminum plate to maintain a certain narrow distance, through the scale read out this distance. Then use the capacitance meter crocodile clip ends clamped in the corresponding position of the aluminum plate, the capacitance meter units adjusted to pf, read out the number of signals at this time. Then adjust the distance between the plates, repeat the above operation, part of the results recorded as shown in Table 1. From the table, it can be seen that as the aluminum plate spacing is reduced by 1 cm in turn, the capacitance of the parallel plate capacitor made is rising.

Table 1. Record of experimental results(Ⅰ)

Aluminum plate spacing(d)/cm	Reciprocal of aluminum plate spacing(1/d)/cm-1	Capacitance(C)/pf
10.00	0.10	6.93
9.00	0.11	7.36
8.00	0.13	7.98
7.00	0.14	8.94
6.00	0.17	9.97
5.00	0.20	11.28
4.00	0.25	13.59

3) parallel plate capacitors and the relationship between the area between the plates squarely. So that the aluminum plate to maintain parallel, completely opposite and narrower distance, between the capacitance meter crocodile clips clamped at both ends of the aluminum plate at the corresponding location, adjust the capacitance meter unit, read out the number of this time. And then move the position of the outer aluminum plate, so that the area between the aluminum plate is reduced, repeat the above operation, part of the experimental results recorded as shown in Table 2. From the table, it can be seen that in the process of reducing the square area S of the aluminum plates from 400cm^2 to 95cm^2, the capacitance of the parallel-shift capacitor is consistent with its direction of change.

Table 2. Record of experimental results(Ⅱ)

Opposite product (S)/cm^2	Capacitance(C)/pf
400.00	29.34
350.00	28.27
300.00	26.39
250.00	24.28
200.00	22.76

150.00	21.94
100.00	18.37
95.00	16.22

4) Parallel plate capacitor with dielectrics. Place a plexiglass of a size slightly larger than the aluminum plate between the metal plates. The capacitance meter alligator clips on the corresponding ends of the metal plate, adjust the units of the capacitance meter, read out the readings at this time, record the results of the experiment. After recording, keep the area of the aluminum plate and the distance between the plates unchanged, pull out the plexiglass plate and replace it with the same size cardboard, and clip the crocodile in the corresponding position. Pull out the cardboard, adjust the units of the capacitance meter and read out the reading at this point. Experiment with a copper plate to keep the spacing of 1.5 cm unchanged, the aluminum plate directly opposite the area S gradually decreases, record the experimental results data. Table 3 for the copper plate $d = 2mm, S = 400cm^2$, change the copper plate between the medium of the experimental results. From the table it can be seen that under the same conditions, the capacitance of the parallel plate capacitor due to different media between the existence of large differences. Table 4 for the copper plate $S = 400cm^2$ unchanged, the distance between the aluminum plate d sequentially reduced 1 cm part of the experimental results, the data in the table show that the capacitance of the parallel plate capacitor and the distance between the aluminum plate still shows the opposite trend. However, the capacitance using copper plates shows an increasing effect compared to aluminum plates.

Table 3. Record of experimental results(III)

Dielectric	Capacitance(C)/pf
Cardboard	442.67
Organic glass	348.29
Air	151.83

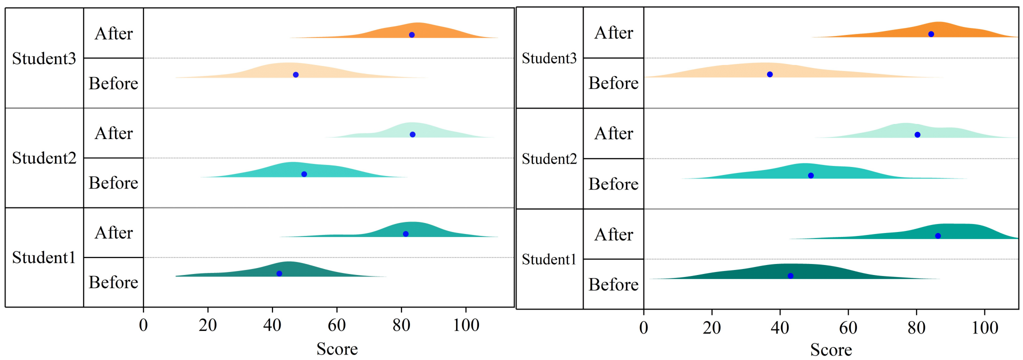
Table 4. Record of experimental results(IV)

Aluminum plate spacing(d)/cm	Reciprocal of aluminum plate spacing(1/d)/cm-1	Capacitance(C)/pf
10.00	0.10	7.12
9.00	0.11	7.83
8.00	0.13	8.59
7.00	0.14	9.46
6.00	0.17	11.83
5.00	0.20	13.27
4.00	0.25	19.38

To summarize, from the teaching aids made in this paper, it can be concluded that the capacitance C is negatively correlated with the distance between the plates d when the dielectric and S are kept constant. Keeping the dielectric and d certain, the capacitance C and S are positively correlated. Keeping S and d constant, the capacitance is related to the dielectric between the plates. The production of this teaching aid is aimed at integrating the knowledge of physics, engineering, mathematics and other disciplines, cultivating students' practical ability and innovative thinking, and is suitable for secondary school physics science education and STEAM project-based learning.

5.3. Implementation and impact assessment

The selected teaching aid design scheme was made into physical teaching aids, and applied to the popular science education curriculum of middle school physics and STEAM project-based learning activities. The effectiveness of the use of teaching aids was evaluated through classroom observation, student questionnaire surveys and academic performance analysis. Figure 3 shows the statistical results of class interest and course performance of 3 randomly selected students before and after the use of teaching aids, and (a) and (b) represent the comparison results of course interest and course performance respectively. Students' interest in the course was quantitatively measured according to the relevant items in the questionnaire, among which "very interested" was scored as 40 points, "somewhat interested" was recorded as 30 points, "relatively uninterested" was recorded as 20 points, and "very uninterested" was scored as 10 points. As can be seen from the figure, after using the scheme for the production of teaching aids, students' interest in the course has increased significantly, and the course performance has also increased significantly. The effectiveness and feasibility of the design path of teaching aids based on multi-objective programming in this paper are demonstrated.



(a) Course interest (b) Course score

Fig. 3. Implementation effect

6. Conclusion

In this paper, we use multi-objective planning to construct an interdisciplinary teaching aid design path, and use multi-objective genetic algorithm to solve the path. The results of the study show that adopting the “mathematics and electricity integration” scheme for the design of teaching aids for parallel board circulators can achieve the organic balance of maximizing the integration of subject knowledge, maximizing the effect of students' ability cultivation and minimizing the cost under the constraints. According to the optimal solution of the model to design the parallel board circulators and apply them in teaching practice, the students' interest in the course and the overall score of the course performance increased from 40 to 80, which indicates that the model in this paper is able to effectively solve the interdisciplinary teaching aids design path that has a significant effect on students' ability cultivation in the science popularization education and the STEAM project-based learning.

About the Authors

Jin Ziwei holds a Bachelor's degree in Industrial Design from Shanghai Second Polytechnic University and a Master's degree in Mechanical Engineering from Hubei University of Technology. His primary research interests are in STEAM (Science, Technology, Engineering, Art, and Mathematics) education for children, with a particular focus on integrating design thinking into educational practices. During his graduate studies, Jin actively participated in numerous design competitions and received several prestigious awards. Notably, he won the 2024 National College Innovation Competition Dongfang Design Award and the 2022 Milan Design Week Competition. These experiences have significantly shaped his understanding of the intersection between design and education.

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