Causal Inference for BOPPPS Instructional Model Continuous Improvement Programs

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***Abstract*—In response to the requirements of the Ministry of Education for the construction of national first-class courses, and to promote the deep integration of teaching mode innovation and scientific evaluation, this study focuses on the optimization of the BOPPPS teaching mode, which is widely used in engineering and medical education because of its goal-oriented and closed-loop feedback design, but relies on teachers' experience in teaching adjustment and is prone to confuse the correlation and causality between measures and effects. For this reason, this study takes the front door criterion and counterfactual inference of causal inference science and migrates them to be applied to education, mediated elimination of confounding and counterfactual inference are used to optimize the BOPPPS model, and exploring a continuous improvement scheme using an information security course as an example. The results show that the improved model significantly improves the rationality of experimental design and teaching effectiveness, helps teaching decision-making shift from experience-driven to data-driven, meets the national curriculum standard of civic-political integration, and provides an innovative paradigm for the accreditation of engineering education.**

***Keywords*—BOPPPS teaching model, pedagogical reform, counterfactual reasoning, causal inference**

I. INTRODUCTION

As a student-centered closed-loop instructional design framework, the BOPPPS teaching model constructs a "goal-oriented-diagnostic feedback-dynamic adjustment" teaching path through the systematic linkage of six modules: Bridge-in, objective, pre-assessment, participatory learning, post-assessment, and summary. The teaching path of "Goal Oriented – Diagnostic Feedback – Dynamic Adjustment" is constructed. It is proposed by the Canadian Teachers' Skills Training Workshop, based on the theory of constructivism, emphasizing the visual disassembly of teaching objectives and the deep activation of students' participation [1]. BOPPPS has been widely used in the fields of engineering education, medical education, language teaching and so on, and as a teaching model, it is often used in conjunction with other teaching measures. Lou [2] explores the application of the teaching model in the field of curriculum ideology using microbiology course as a carrier. Zhou [3] combines traditional teaching with digital teaching by combining the blended teaching mode, which is practiced in the automobile mechanics course. Dong [4] used both rain classroom and BOPPPS teaching mode in the physical chemistry of materials course, thus improving the teaching effect. Zhang [5] promotes teaching reform based on the application of OBE concepts to the Western Economics course.

However, the BOPPPS model still faces a double challenge in practical application. First, teaching adjustment is highly dependent on teachers' empirical judgment and lacks objective data support. Teachers often design classroom activities based on intuition, but it is difficult to accurately capture students' real needs for instructional strategies, resulting in insufficiently targeted improvement measures. Second, this model is prone to confuse the correlation and causality between instructional interventions and their effects, for example, attributing the improvement of student performance after the implementation of group discussion to the activity design, and ignoring the influence of confounding factors such as independent learning outside the classroom or adjustment of the difficulty of the curriculum. This attribution bias makes teaching optimization fall into empiricism and restricts the sustainable improvement of teaching quality [6].

Aiming at the dilemmas of the traditional BOPPPS instructional model, which relies on teachers' experience and has ambiguous causal attribution, this study innovatively integrates the science of causal inference into the educational design and constructs a data-driven improvement paradigm. Based on Judy Pearl's structural causal model and counterfactual logic, we propose a dual-path methodology of "mediation to eliminate confounding" and "counterfactual inference": the former introduces standardized assessment observation points (e.g., "experimental design logic") as a mediating variable, and the former introduces standardized assessment observation points (e.g., "experimental design logic") as a mediating variable. By introducing standardized assessment observation points (e.g., "logic of experimental design") as mediating variables, the former can block the interference of confounding factors

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such as teacher preference on teaching interventions, and reconstruct the pure causal chain of "teaching interventions-mediating indicators-competence goals", for example, by using the standard formula of the front door to transform the assessment of teaching effectiveness into a quantifiable mathematical process. For example, we use the standard formula of the front door to transform the assessment of teaching effectiveness into a quantifiable mathematical process; the latter constructs a multi-period dynamic model to simulate counterfactual scenarios such as the failure to implement tiered homework, and analyzes the potential loss of students' competence enhancement in a comparative manner, so as to establish a verifiable causal chain between educational interventions and learning effectiveness. The combination of the two breaks through the limitations of statistical relevance, realizes the leap from empirical trial-and-error to evidence-driven teaching strategies, and provides a theoretical tool that combines mathematical rigor and practical explanatory power for solving the problems of goal ambiguity and causal confusion [7].

Compared to the traditional BOPPPS model, the causal enhancement enables a leap in the instructional paradigm. When collecting data in the field of education in the traditional statistical way, a measure needs to be implemented for one year to four years before a preliminary conclusion can be drawn. Using counterfactual inference, a model can be constructed by using data from previous years or data from other schools that have implemented the same measure, so that a reference conclusion can be drawn as a means of deciding whether or not to implement an instructional measure. While analyzing the data, the traditional statistical approach only looks at correlation ignoring causality, leading to a misestimation of the effect of the measure, mediating the elimination of confounding. By contrast, in the implementation stage of the measures, a mediating mechanism can be introduced to eliminate the influence of confounding factors on the effects of the measures as much as possible.

II. Literature Review

Causal inference provides a powerful tool for research and practice in various fields through in-depth analysis of causal relationships between variables. Whether in scientific research, policy making, business decision making, or other fields, causal modeling can help people better understand and solve practical problems, and promote the development and advancement of society. Domingo-Relloso [8] extends multimediation algorithms to the field of survival analysis that making it adaptable to time-to-event outcome studies in survival data. Diong [9] uses causal inference to estimate the causal impact of learning patterns on student performance. Suchinta [10] applies structural causal modeling to ecological studies, combining front-gate adjustment and back-gate adjustment to de-mix the data. Vonk [11] proposes a hypothetical how to make causal inference of methods from non-parametric and parametric demonstrations and further advances the study of causal discovery. Glass [12] explores the importance of causal inference in public health, describing the evolution from the classical causality framework to the modern potential outcomes framework and emphasizing the application of these methods in evaluating interventions and solving complex public health problems. Daniel [13] proposes that, in the presence of multiple mediating variables Counterfactual definitions and methods for conducting causal mediation analyses, discusses effect identification under strong assumptions, and empirically analyzes them with household study data. Hicks [14] describes how to estimate and sensitize analyses of causal mediation effects, providing the correct methodology for their computation under a wide range of statistical models. Hong [15] systematically describes the use of causal inference in social science research, covering moderating effects, mediating effects and spillover effects in theory and methodology.

III. Materials and Methods

The science of causal inference is an interdisciplinary field that reveals causal relationships among variables through a systematic methodology that centers on going beyond statistical correlations to identify the true impact of instructional interventions on outcomes. The structural causal model and causal graph theory proposed by Judy Pearl visualize and formalize causal relationships through mathematical tools, systematize the control of confounding variables and the identification of intervention distribution mechanisms, and enable the optimization of educational strategies and the design of athletic training to shift from experience-driven to data-driven scientific decision-making, providing a reliable paradigm for causal attribution in complex systems.

A. Increased Intermediation to Eliminate Confounding

The Front Door Criterion in causal inference allows for the separation of causal effects through mediating variables when confounders are unobservable [16]. "Adding a Mediator to Eliminate Confounding" is a methodological innovation that transfers Judy Pearl's Front Door Criterion from causal science to the field of educational design, which centers on blocking unobserved confounders (C) from interfering with instructional measures (X) and students' abilities (Y) through the introduction of a mediating variable (M), which can be used to reconstruct causal diagrams:

a. Build the original model: there are confounding paths ($X \leftarrow C \rightarrow Y$) between instructional measures (X) and student abilities (Y), such as unobserved factors (C) such as teachers' subjective preferences and students' background differences.

b. Mediator introduction: By designing standardized assessment observation points (M), such as "research design logic" and "AI tool normality", the causal path of ($X \rightarrow M \rightarrow Y$) is constructed, blocking the direct interference of C.

c. Simplify the causal graph: after the conditions are met, remove the mixed paths from C to X and Y, and keep only the pure path (X → Y).

The steps a, b, and c are shown in Fig. 1.

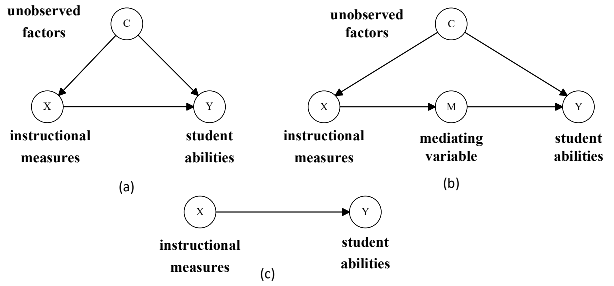

Fig. 1. Causal map increased mediator elimination confounding.

B. Counterfactual Inference

Counterfactual inference is the core approach to causal science proposed by Judy Pearl, whose goal is to answer the question "How would the outcome have changed if different interventions had been made?" by constructing a structural causal model. The core steps include:

Outreach: The use of observational data to estimate the distribution or specific values of exogenous variables.

Intervention: Modification of the model by the do operator to simulate counterfactual hypotheses.

Prediction: Calculating potential outcomes based on the modified model and exogenous variable estimates.

The core logic of counterfactual inference is common to both the educational and causal domains, and both rely on the theoretical underpinnings of structural causal models. However, there are still dynamic and complex issues to be resolved when applied to education, e.g., education needs to deal with multi-period, non-linear causal chains, while the causal domain is more concerned with static effect separation. Therefore, temporal extensions should be made in education, and dynamic counterfactual models need to be constructed for multi-period teaching improvement:

Year 1 (past tense): Identify problems based on evaluation data and propose improvements.

Year 2 (present tense): Evaluating new data after implementation, analyzing the effects of improvements, and proposing new continuous improvements.

Year 3 (in the future): Reduce the cost of trial and error through counterfactual inferential analysis.

Fig. 2 shows the measures for each of the three years.

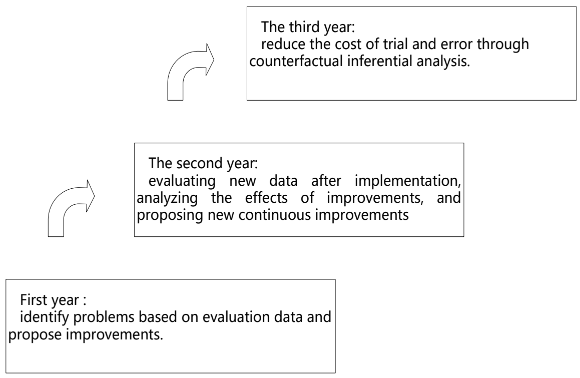

Fig. 2. Continuous improvement of multi cycle teaching.

IV. Result and Discussion

Taking this year's information security course instruction as a case study, this paper provides a detailed exposition of the Causal Inference framework applied to the BOPPPS Instructional Model.

1. Bridge-in

In the course introduction, a convergence education is introduced. Convergence education is driven by compelling or complex socio-scientific problems, problems or topics, where learners apply knowledge and skills using a blended approach across multiple disciplines to create and innovate new solutions. Before the beginning of each chapter, the teacher will give the chapter related social issues, such as "In recent years, the wind power industry due to excessive competition led to wind turbine equipment prices "brainless down", corporate profit margins compression, and even the phenomenon of low price to win the bid, at the expense of the quality of the phenomenon. 2025 the central economic work conference has been the central economic work conference in 2025 has clearly rectified the "involutional" competition as a key task, through policies and regulations to regulate market behavior, balance the development of the industry and resource efficiency. Why does industry need to develop communication security standards? What is the role of the IEC 62351 standard for the wind power industry?" Through the real existence of real problems in society and closely related to professional knowledge to enhance students' learning motivation, reflecting the "national first-class course evaluation standards" index 3 "content with the times", adapting to the wind farm monitoring and communication security solutions, to realize the multidisciplinary needs of this topic.

2. Objective

The establishment of learning objectives is divided into knowledge objectives, ability objectives and quality objectives from the perspective of enhancing students' learning ability. First, the knowledge objective requires students to be able to comprehensively utilize information security knowledge and technology to build solutions to realize the functions of identity authentication, access control, communication security, intrusion detection and so on according to the needs of information security protection level of the actual communication network engineering, and to be able to use analogical migration, metacognition, and to embody the sense of innovation in designing sessions. Second, the competency objective requires students to be familiar with communication network information security standards and solutions, understand the importance of complying with communication network security standards and laws and regulations, and be able to analyze and evaluate the impact of information technology engineering practices on society, health, safety, law, and culture. Thirdly, the quality objective requires students to be able to use intellectual reasoning tools to design information security testing experiments, and to be able to judge and evaluate the damage and potential hazards that may be caused to human beings and the environment during the product cycle based on the solutions and experimental results. They should be able to express their personal opinions clearly through written reports and oral presentations on complex engineering issues of information security, and have some English presentation skills to communicate and exchange ideas in a cross-cultural context.

3. Pre-assessment

Before the classroom teaching, the teacher gives some solutions and literature to solve the social problems in the introductory session, such as the network architecture of Inner Mongolia wind farm undertaken by Xiangdian Wind Energy, assigns homework, and lets the students form their own groups of 5 to 8 people to interact these solutions and literature with the AI, so that the AI can design the network security and prevention system solutions, which can realize the Xiangdian Wind Energy engineers' remote access to the operational data of the wind farm or the specific individual wind turbine server operation data, to ensure the compromise and consistency of technology, security and cost. Finally, based on the content of the AI's response, combined with the relevant content of the textbook, based on their own interests, to design compelling social realities of complex problems driven by the integration of super-disciplinary innovative solutions. This can be a wind power domain cybersecurity problem or other domains of interest, during which the AI's cross-disciplinary migration capabilities need to be fully utilized to migrate the AI-generated cybersecurity solution for the wind power domain to solving other domains of security problems. Students can complete the assignment to preview the knowledge of the textbook, to understand their own professional knowledge, and to increase the ability of AI interaction. Teachers, on the other hand, can adjust the focus of the lecture content through the performance of students.

4. Participatory learning

Participatory learning is the core of teaching, after students complete the front side of the homework, the class will select an outstanding homework for the class to present a PowerPoint, exam review questions and debate video. ppt is a compelling solution to a complex social reality generated by the students in the pre-assessment, combining the AI interactive content and the relevant knowledge of the textbook. The exam review questions are 5 exam review questions based on the solutions and previous exams, which can be multiple choice, judgment, fill-in-the-blanks, calculation questions, etc. Students are required to write down the questions, reference answers, scoring criteria, the basis of the questions, and the core investigation points. Through the students' own questions, we can ensure the cornerstone role of the basic disciplines and enhance the degree of mastery of specialized knowledge. Debate video is designed by students to design an information security classroom students from disagreement to gradually reach a consensus on the debate script, and by the group of students to rehearse the video recording. The positive and negative sides take turns to speak on a controversial social issue, put forward their own views, and finally both sides summarize the commonalities of their views and reach a consensus, thus improving the ability to improve the critical thinking and preventing the students from interacting with the AI once and then not making continuous improvement, thus ensuring self-regulated learning.

Fig. 3 illustrates how to eliminate AI abuse using mediating variables in a causal map.

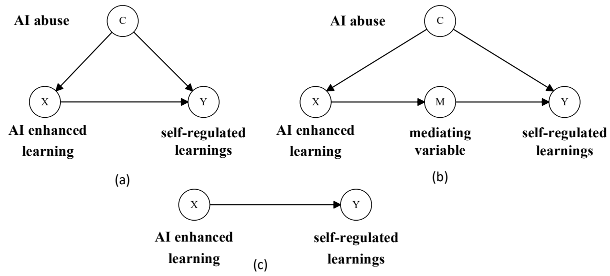

Fig. 3. Causal map of participatory learning.

The presentation is followed by an evaluation by the leader of the best work group from another class, i.e., evaluating the strengths and weaknesses of the work and describing how the strengths of the work can be transferred and the weaknesses can be improved. Student evaluation increases student participation and allows all students to learn about the different aspects of good work, thus improving their abilities in multiple dimensions.

5. Post-assessment

At the end of the participatory learning, the instructor issues an accompanying quiz for students to complete in a limited amount of time, and announces the answers and explains them upon completion. The accompanying quizzes were divided into objective questions designed based on the knowledge of the textbook to examine the effectiveness of students' learning and depth of understanding of professional knowledge through classroom learning, and subjective questions that required students to analyze excellent assignments using a metacognitive protocol to examine students' critical thinking skills. The steps of the metacognitive protocol are (1): Awareness: Identify potential problems or influences in the existing system. (2): Diffusion: Look for similar scenarios or variables from different perspectives or domains. (3): Disruption: Challenge the existing assumptions or structures and propose new interventions or paths of analysis.

Fig. 4 shows how to eliminate rote learning using metacognitive protocols in a causal map.

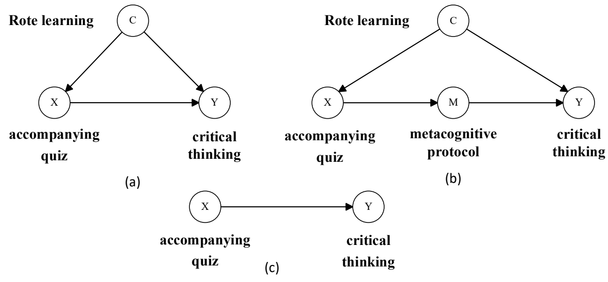

Fig. 4. Causal map of post-assessment.

6. Summary

At the end of the class, the teacher assigns post-course exercises based on the knowledge related to the textbook in the students' participatory learning to deepen their understanding and memorization of the knowledge points. Moreover, when answering the questions, students are not limited to the content of the textbook, but apply the solutions to social problems to solve the questions in order to increase their professional knowledge and enhance their critical thinking at the same time.

The analysis of information security course assessment outcomes indicates that the 21st-grade cohort, comprising 103 students, attained a mean score of 82.8 with a standard deviation of 19.13 and a median of 90.6. In contrast, following the implementation of the BOPPPS pedagogical model, the 22nd-grade cohort, consisting of 145 students, demonstrated a statistically elevated mean score of 85.6, accompanied by a standard deviation of 19.80 and a median of 97.5. The data indicate that the new model enhanced active classroom engagement for most students, with the significant upward shift in median scores suggesting stronger concentration of grades in higher ranges. However, the increased standard deviation reflects greater score dispersion, likely attributable to a subset of students accustomed to traditional passive learning who struggled to adapt to participatory pedagogy. This divergence amplified the performance gap, creating a polarized outcome: proactive participants demonstrated marked improvement, while resistant learners stagnated, resulting in distinct academic stratification.

Fig. 5 demonstrates how the BOPPPS framework enhances students' abilities.

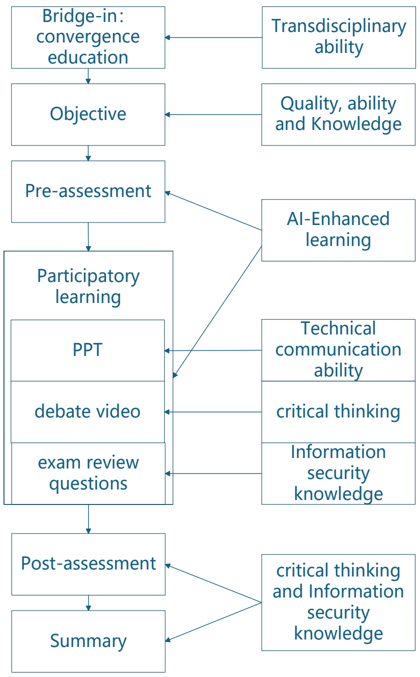

Fig. 5. Intervention measures in the BOPPPS model and the corresponding student abilities.

V. Conclusion

By integrating the "mediated disambiguation" and "counterfactual inference" methodologies in causal inference science into the BOPPPS teaching model, this study constructs a data-driven continuous improvement framework, which effectively solves the pain points of the traditional model that relies on the teacher's experience, causal attribution, and ambiguity. It effectively solves the pain points of the traditional model, which relies on teachers' experience and causal attribution. By introducing standardized assessment observation points as mediating variables, we block the interference of confounding factors on teaching interventions, and reconstruct the pure causal path; meanwhile, we use counterfactual inference to quantify the real impact of teaching measures and reduce the cost of trial and error.

Future research can be expanded in the following directions: first, enhance the learning motivation of students trapped in traditional learning styles through grouping tasks; second, apply this framework to more subject areas to explore the universality of this methodology; third, enhance the real-time adaptive adjustment of teaching strategies by combining with AI technology, for example, after learning the wind farm scenarios, students can propose wind farm scenarios that are different from the real ones with the assistance of AI, and then look up information by finding information and AI assistance, construct a counterfactual model, and then write a code to calculate the effect of this scheme, so as to improve the immediacy and practicality of teaching.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Yao Xiao wrote the paper and conducted the research; Bin Duan contributed to proposing the research idea and guiding the direction; Yi Kuang assisted in revising the paper; all authors had approved the final version

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