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Machine learning-based multidimensional evaluation of the effectiveness of course civics teaching: a case study of the occupational health and occupational medicine course

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Introduction: This study investigated the integration of Course-based Ideological and Political Education (CIPE) into Occupational Health and Occupational Medicine (OHOM) courses within the "Internet Plus" context. The aim was to evaluate its impact on students' academic performance, professional ethics, and social responsibility.

Methods: A total of 230 questionnaires were distributed to senior undergraduate students at Guilin Medical University, with 220 valid responses collected (response rate: 95.6%). Data were analyzed using Python 3.11 and R 4.1.1. Statistical methods included descriptive statistics, *t*-tests/non-parametric tests, chi-square tests, and multiple linear regression with adjustment for gender and age. Machine learning methods (XGBoost, random forests, and support vector regression) were combined with five-fold cross-validation and SHAP analysis for model optimization and interpretation.

Results: Students in the CIPE-integrated group achieved significantly higher composite scores (83.90 ± 3.08) than the traditional group (82.66 ± 4.28, $p < 0.05$). Regression analysis identified course returns ($\beta = 0.54$, 95% CI: 0.16–0.92), group participation ($\beta = 0.44$, 95% CI: 0.03–0.84), online resource utilization ($\beta = 0.46$, 95% CI: 0.05–0.87), and ethical benefits ($\beta = 0.52$, 95% CI: 0.12–0.92) as significant predictors of performance. SHAP analysis highlighted the critical roles of group participation, course motivation, ethical benefits, and note review, while also revealing individual differences in learning behaviors and value formation.

Discussion: The deep integration of CIPE into OHOM courses through blended teaching significantly enhanced students' academic outcomes, professional ethics, and social responsibility. The combined use of traditional statistical methods and interpretable machine learning provided robust evidence for evaluating educational interventions and offered methodological guidance for extending CIPE applications in preventive medicine and public health curricula.

KEYWORDS

ideological and political education, higher education, occupational health and occupational medicine, educational innovation, machine learning

1 Introduction

Establishing moral integrity and cultivating talent are central to fulfilling higher education's fundamental mission. As a key approach to this mission, Curriculum-based Civic and Political Education (CIPE) is progressively extending from ideological-political theory courses into diverse professional disciplines (Wang and Peters, 2021).

However, its systematic implementation within core medical curricula remains insufficiently explored. Rooted in Marxist theory and socialist core values, CIPE emphasizes cultivating students' moral awareness, social responsibility, and national identity while developing their professional competencies (Ding et al., 2023), however, existing research has primarily focused on macro-level policies or individual case studies, with limited systematic empirical analysis specific to medical education curricula.. This integration is particularly imperative in medical education, cultivating healthcare professionals who merge technical mastery with robust ethical principles and humanistic awareness essential for public service (Guo et al., 2020). However, data-driven evidence remains scarce on how the dual cultivation of technical skills and values can be effectively achieved through the curriculum system. The Internet Plus initiative unlocks opportunities for blended learning to integrate CIPE into professional core curricula via adaptive assessment, digital resources, and interactive design (Zeng, 2022). This study examines the Occupational Health and Occupational Medicine (OHOM) course – a core discipline in preventive-medicine training that inherently addresses professional ethics, health equity, and legal responsibility. By developing multidimensional evaluation systems through machine learning, we demonstrate how blended learning frameworks effectively implement CIPE, revealing data-driven synergies between professional expertise and ideological cultivation in the digital era.

1.1 Current status and challenges of implementing civics education in the OHOM course

As higher education institutes implement CIPE initiatives nationwide, medical curricula now systematically integrate ideological-political components into specialized courses to advance holistic education (Wang et al., 2022). As a core component of the Preventive Medicine curriculum, OHOM provides an organic platform for CIPE integration. Its inherent focus on professional ethics, humanistic care, and social responsibility creates a pedagogical pivot that bridges medical ethics education with professional practice (Abudoukeremu, 2024). Most institutions currently attempt initial curricular integration of ideological-political education within OHOM instruction, representing preliminary efforts to bridge specialized knowledge with civic values. For instance, when teaching occupational disease prevention and hazard management, faculty guide students to contemplate "people-centered, health-first" medical ethics while emphasizing physicians' social responsibility for safeguarding workers' health. This pedagogical integration cultivates students' sense of social responsibility and professional purpose, enabling their transition from technology-centric to value-driven learning perspectives (Roux et al., 2021). Pedagogically, select universities now actively implement "Internet +" teaching paradigms—leveraging synchronous digital lectures, virtual simulation labs, and collaborative discourse platforms—to reconfigure medical education delivery. These digital pedagogies proved particularly impactful during the pandemic, ensuring instructional continuity while diversifying teaching methods in medical education (Li et al., 2025; Liu, 2021). The integration of CIPE within OHOM curricula continues advancing systematically—manifested through specialized content design, mixed-mode pedagogical delivery, and holistic conceptual integration—ultimately establishing an integrated framework for developing clinicians with clinical-professional integrity and demonstrable social accountability.

Despite observable progress in course development, significant challenges persist in current pedagogical practice. Primary among these is the superficial implementation of "Internet +" methodologies: while some institutions employ online modules and virtual experiments, most applications remain confined to passive resource dissemination (e.g., video lectures) without interactive mechanisms addressing occupational health's contextual demands. Crucially, this digital scaffolding fails to simulate authentic workplace scenarios, impairing the development of occupational risk assessment competencies and reducing both student engagement and instructional efficacy. Second, while curricula increasingly incorporate ideological-political education elements, implementation remains predominantly superficial. Integration lacks depth, as evidenced by disjointed classroom references to professional ethics and public responsibility—often reduced to isolated remarks rather than a cohesive conceptual framework. Moreover, pedagogical strategies fail to establish meaningful synergies with occupational health content, resulting in underdeveloped student identity formation and compromised educational effectiveness. Compounding these issues, assessment continues to prioritize traditional closed-book examinations while neglecting essential competency evaluation. The absence of a diversified process evaluation system also impedes teachers' ability to obtain timely feedback and optimize teaching strategies.

1.2 Implications of promoting CIPE in preventive medicine education

Systematically promoting CIPE in preventive medicine education holds significant practical importance. Preventive medicine, as a highly public and policy-oriented branch of medicine, requires practitioners not only to master knowledge of population health prevention and control but also to possess strong professional ethics, humanistic qualities, and a sense of social responsibility. Integrating ideological and political education into core courses such as "Preventive Medicine" and "OHOM" can guide students to develop a comprehensive understanding of the medical concept of "people's health as the center," enhance their systematic cognition of health equity, social governance, and public service, and promote the reciprocal enhancement of professional competence and ideological quality to realize the principle of "moral competence and policy-oriented medical science." To achieve the goal of educating individuals with both virtue and ability, advancing in both skill and ethics, CIPE strategically integrates core societal values—including public welfare consciousness, social justice principles, and professional ethical imperatives—into pedagogical design. This systematic integration guides students to internalize the "people-centered, life-first" value paradigm while fostering demonstrated commitment to serving grassroots populations and advancing collective wellbeing

(Tang, 2021). In the contemporary landscape characterized by intensifying global health risks, normalized management of major infectious diseases, and escalating occupational health challenges, preventive medicine confronts unprecedented multidimensional pressures. These evolving demands necessitate professionals equipped not merely with robust epidemiological expertise but also with fortified ideological conviction and systemic perspective—capacities essential for navigating complex public health crises while maintaining ethical coherence in population-level decision-making (Krousel-Wood, 2023). By strategically integrating the Healthy China 2030 framework, contemporary national health policies, historical public health missions, and exemplary practitioner narratives, CIPE fosters sustained professional development while deepening students' critical awareness of health's societal determinants. As medical education evolves from knowledge-transfer paradigms toward integrated competency-literacy-values formation, CIPE emerges as the essential pedagogical catalyst for cultivating internationally competitive public health leaders equipped to address complex population health challenges. CIPE has emerged as an essential pedagogical foundation for cultivating high-caliber public health professionals. By systematically integrating national core values, legal compliance awareness, professional ethical frameworks, and civic responsibility commitments throughout instructional delivery, CIPE fosters the development of integrated professional identity formation while simultaneously advancing critical health-equity analysis capabilities, interdisciplinary collaboration competencies, and community-engagement literacies, ultimately enhancing both the technical proficiency and societal responsiveness of preventive medicine practitioners within complex health ecosystems (Eidt, 2023).

Moreover, confronting contemporary challenges—including recurrent public health emergencies, persistent urban-rural health resource disparities, and escalating chronic disease burdens—CIPE pedagogically scaffolds students' integration of individual wellbeing within tripartite societal frameworks: national developmental objectives, population health imperatives, and health equity paradigms. This pedagogical approach concurrently cultivates historical consciousness regarding public health's societal role while strengthening actionable commitments to community service and population health stewardship (Meng and Xu, 2014; Organization, 2023). Consequently, CIPE constitutes not merely the organic evolution of value-based pedagogy within preventive medicine, but more critically, an essential structural reinforcement and strategic implementation mechanism for constructing high-caliber preventative health education systems in the contemporary era—simultaneously furnishing the talent infrastructure and ideological foundations necessary for realizing the globally articulated "Health for All" imperative (Tulchinsky et al., 2015).

1.3 Feasibility of integrating CIPE into the course of OHOM in the context of "internet +"

With the rapid development and widespread application of "Internet+" technology, digital and intelligent teaching platforms are gradually becoming important carriers of higher medical education. The integration of CIPE into the course of OHOM, facilitated by innovative Internet-based teaching methods, not only enhances the interactivity and flexibility of instruction but also creates favorable conditions for the organic integration of civic and political education with professional courses. Internet technology can effectively enhance students' understanding of complex occupational health knowledge while simultaneously strengthening their sense of social responsibility and professional ethics (Liu, 2024). In this context, CIPE can convey ideological and political education content more intuitively and vividly through diverse methods such as online teaching resources, case studies, and virtual simulations, thereby enhancing students' value identity and practical abilities (Verkuyl et al., 2024). Furthermore, Internet-facilitated blended pedagogies transcend the spatiotemporal constraints inherent to traditional classroom-based instruction, enabling the seamless and dynamic infusion of ideological-political education (IPE) across the continuum of professional health sciences training (Wang et al., 2025). The application of online platforms promotes teacher–student interaction and collaboration, enhancing students' independent learning abilities and critical thinking skills, which plays a crucial role in improving both their ideological-political literacy and professional competence. Simultaneously, through data analysis and learning tracking, teachers can more accurately assess students' learning status and ideological dynamics, thereby enabling personalized ideological and political guidance and optimizing teaching strategies (Zhang, 2024). It is worth noting that research on the in-depth integration of CIPE with medical professional courses in the context of "Internet+" remains relatively limited, particularly in the field of OHOM, where practical applications are still in their infancy. In response to this status quo, some universities have begun to integrate online case teaching with CIPE courses by utilizing cases of occupational health incidents to enhance students' understanding and recognition of CIPE topics such as professional ethics, social responsibility, and health equity through online discussions and interactions. These explorations demonstrate that, in the context of "Internet+," the integration of CIPE is not only technically feasible but also offers significant potential for innovation in teaching concepts and practical methods (Huang and Weiqi, 2024; Wang, 2022). To more effectively examine these pedagogical innovations, it is essential to ground CIPE in established theoretical frameworks that elucidate how ethical identity and professional values can be cultivated in higher education.

1.4 Theoretical basis for CIPE integration of OHOM programmes

The integration of CIPE into medical and public health education can be situated within three interrelated educational traditions: critical pedagogy (Garavan, 2016), which views education as a means of fostering critical awareness and empowering socially responsible professionals; transformative learning theory (Paprock, 1992), which explains how learners' frames of reference are transformed through critical reflection on

civic and ethical issues; and moral development theory (Anderson and Burchell, 2021), which describes the progression from rule-based to principle-based moral reasoning. These perspectives offer a conceptual foundation for understanding how CIPE cultivates moral identity and professional values, and they provide a framework for evaluating the CIPE programme in this study.

Based on the above background and theoretical framework, this study focuses on three core research questions: (1) Does the integration of CIPE significantly enhance students' academic performance? (2) Does such integration contribute to the development of students' moral identity and professional values? (3) Which learning behaviors are most predictive of students' overall quality scores? Accordingly, the following hypotheses were proposed: H1: Students in the CIPE integration group will demonstrate significantly higher overall performance compared to those in the traditional teaching group. H2: CIPE integration will have a significant positive impact on students' moral identity and professional values. H3: Positive learning behaviors (e.g., group participation, use of online resources) will significantly predict higher overall quality scores. To examine these questions and test the hypotheses, a total of 230 questionnaires were distributed to senior students at Guilin Medical College, with 220 valid responses collected, yielding an effective response rate of 95.6%. The questionnaire comprised six modules: learning attitude; learning methods and strategies; emotional commitment; interaction and cooperation; use of course resources; and understanding of Civics content. These modules addressed various aspects of learning behavior, course experience, and value recognition. The questionnaire aimed to assess the effectiveness of Civics integration from the students' perspective and to provide a theoretical and practical reference for the further advancement of Civics integration in the preventive medicine curriculum.

2 Methods

2.1 Research design and target population

This study adopted a cross-sectional survey design. Participants were fourth-year undergraduate students majoring in Preventive Medicine and non-Preventive Medicine at Guilin Medical University, all of whom had completed the relevant coursework. The sample was obtained through convenience sampling and included students from diverse academic backgrounds to ensure comparability.The inclusion criteria were as follows: (1) undergraduate students aged ≥18 years; (2) completion of Preventive Medicine or related core courses; and (3) voluntary participation with signed informed consent. The exclusion criteria were: (1) incomplete questionnaires or logical inconsistencies; (2) failure to complete the questionnaire within the stipulated timeframe; and (3) duplicate submissions.

A total of 230 questionnaires were distributed. After collection, 10 were excluded due to missing values or inconsistencies, resulting in 220 valid responses for analysis, corresponding to a 95.6% response rate. Sample size determination was informed by previous studies in this field (Shen et al., 2025; Varkey et al., 2011), and a pre-test power analysis conducted using G*Power 3.1 software. With a medium effect size ($f = 0.25$), significance level $\alpha = 0.05$, and test power = 0.80, the minimum required sample size was approximately 180 participants. The final effective sample size ($n = 220$) exceeded this requirement, ensuring sufficient statistical power.

2.2 Tools and measurement indicators

Data were collected using a self-administered structured questionnaire consisting of three parts: basic information, course behavior-related variables, and the Course Civics Acquisition Sense Scale. Both the course behavior variables and all items in the Course Civics Acquisition Sense Scale employed a 5-point Likert scale, where participants rated each item according to their own experiences, with scores ranging from 1 to 5; higher scores indicated stronger corresponding behaviors or feelings. Simultaneously, three objective learning performance indicators were collected—homework score (30% of the total grade), attendance score (30%), and exam score (40%)—which were weighted to generate a continuous comprehensive quality score out of 100 points.

2.3 Reliability and validity tests

Reliability and validity tests were conducted to ensure the stability of the scale's structure. Cronbach's α coefficient was used to assess the questionnaire's reliability, while the KMO measure of sampling adequacy and Bartlett's test of sphericity were employed to evaluate the scale's suitability for factor analysis. The analysis indicated that the scale demonstrated good internal consistency ($\alpha > 0.8$) and acceptable structural validity (KMO > 0.7, Bartlett's $p < 0.001$).

2.4 Methods of statistical analysis

Data analysis was conducted using Python 3.11 and R 4.1.1. The composite score was treated as the dependent variable, while questionnaire variables served as independent variables, with their respective total scores calculated. Descriptive statistics were first performed, including means and standard deviations (mean ± standard deviation). The normality of continuous variables was assessed using the Shapiro–Wilk test, and the homogeneity of variances was examined using Levene's test. For continuous variables meeting both assumptions, independent-samples *t*-tests were applied for univariate analysis; otherwise, Mann–Whitney U tests were used. Categorical variables were analyzed using chi-square tests or Fisher's exact tests. For multivariate analysis, multiple linear regression models were constructed with questionnaire dimensions as independent variables and overall quality scores as the dependent variable, while controlling for potential confounding factors such as gender and age. To ensure model robustness, regression diagnostics assessed multicollinearity (variance inflation factor [VIF] <

10), residual normality, and homoscedasticity. In the machine learning analysis, three regression models—XGBoost, Random Forest Regression (RFR), and Support Vector Regression (SVR)—were employed. Questionnaire items (covering learning behaviors, course engagement, and perceptions of ideological content) were used as independent variables, while the composite quality-weighted score (comprising assignments, attendance, and examination results) was used as the dependent variable. All models underwent hyperparameter tuning via five-fold cross-validation, optimizing root mean square error (RMSE) as the objective function. Model performance was evaluated using the coefficient of determination (R^2), RMSE, and mean absolute error (MAE).To interpret model outputs, SHAP (SHapley Additive exPlanations) analysis was applied to quantify the marginal contribution of each variable to predictions. Feature importance rankings were visualized using SHAP summary plots and bar charts, thereby identifying the most influential learning behaviors and value-recognition factors. All machine learning analyses were conducted in Python, with key tools including XGBoost (v1.7), scikit-learn, SHAP (v0.42), Matplotlib, and Pandas.

3 Results

3.1 Comparison of basic information of the two groups of students

A total of 220 valid questionnaires were included, all from undergraduate students who had completed the OHOM course. The sample comprised 51.36% female and 48.64% male students; 48.64% majored in preventive medicine, while 51.36% were enrolled in other majors (Table 1).

3.2 Comparison of student performance between the two groups

Regarding academic achievement, the composite score of the traditional teaching group was 82.66 ± 4.28, while that of the Civic and Political Integration Teaching group was 83.90 ± 3.08; the difference was statistically significant ($p < 0.05$) (Table 2).

3.3 Comparison of course behavior and civics dimension scores

The results showed that learning commitment, class focus, note review, course interest, course reward, group participation, use of online resources, moral gain, and moral identity all differed significantly between the two groups ($p < 0.05$). The total scores of the two groups were also significantly different ($p < 0.05$) (Table 3).

3.4 Multifactor analysis of student achievement

Multiple linear regression analysis showed that course rewarding ($\beta = 0.54$, 95% CI [0.16, 0.92], $p < 0.01$), group participation ($\beta = 0.44$, 95% CI [0.03, 0.84], $p < 0.05$), use of online resources ($\beta = 0.46$, 95% CI [0.05, 0.87], $p < 0.05$), and moral gain ($\beta = 0.52$, 95% CI [0.12, 0.92], $p < 0.05$) were significant positive predictors of composite scores. In contrast, variables such as learning commitment, class focus, and note review were not significant, as their 95% confidence intervals crossed zero. Preventive medicine major status also had a positive effect ($\beta = 0.97$, 95% CI [0.07, 1.88], $p < 0.05$), while gender was non-significant. These results highlight that motivational and

TABLE 1 Basic information about the participants.

Characteristic	Total	Traditional teaching group	Civic and political integration teaching group	p
Gender				
Male	107 (48.64%)	51 (46.36%)	56 (53.64%)	0.589
Female	113 (51.36%)	59 (50.91%)	54 (49.09%)	
Is prevent major				
Yes	107 (48.64%)	54 (49.09%)	53 (48.18%)	0.879
No	113 (51.36%)	56 (53.64%)	57 (51.82%)	

TABLE 2 Comparison of student performance between the two groups.

Characteristic	Total	Traditional teaching group	Civic and political integration teaching group	p
Homework score	82.85 ± 6.58	82.08 ± 7.32	83.61 ± 5.67	0.102
Attendance score	83.49 ± 6.49	83.02 ± 7.07	83.95 ± 5.85	0.329
Exam score	83.45 ± 6.63	82.82 ± 7.60	84.09 ± 5.47	0.200
Composite score	83.28 ± 3.77	82.66 ± 4.28	83.90 ± 3.08	<0.05

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TABLE 3 Comparison of course behavior and civics dimension scores.

Characteristic	Score	Total	Traditional teaching group	Civic and political integration teaching group	*P*
Learn commitment	1	21 (9.55%)	11 (10.00%)	10 (9.09%)	<0.01
	2	55 (25.00%)	39 (35.45%)	16 (14.55%)	
	3	72 (32.73%)	36 (32.73%)	36 (32.73%)	
	4	45 (20.45%)	14 (12.73%)	31 (28.18%)	
	5	27 (12.27%)	10 (9.09%)	17 (15.45%)	
Focus class	1	27 (12.27%)	16 (14.55%)	11 (10.00%)	<0.05
	2	60 (27.27%)	38 (34.55%)	22 (20.00%)	
	3	55 (25.00%)	22 (20.00%)	33 (30.00%)	
	4	49 (22.27%)	19 (17.27%)	30 (27.27%)	
	5	29 (13.18%)	15 (13.63%)	14 (12.73%)	
Review notes	1	26 (11.82%)	15 (13.63%)	11 (10.00%)	<0.01
	2	42 (19.09%)	31 (28.18%)	11 (10.00%)	
	3	71 (32.27%)	30 (27.27%)	41 (37.27%)	
	4	55 (25.00%)	25 (22.73%)	30 (27.27%)	
	5	26 (11.82%)	9 (8.19%)	17 (15.46%)	
Course interest	1	26 (11.82%)	16 (14.55%)	10 (9.09%)	<0.05
	2	49 (22.27%)	32 (29.09%)	17 (15.45%)	
	3	70 (31.82%)	35 (31.82%)	35 (31.82%)	
	4	48 (21.82%)	16 (14.55%)	32 (29.09%)	
	5	27 (12.27%)	11 (10.00%)	16 (14.55%)	
Course rewarding	1	25 (11.36%)	14 (12.73%)	11 (10.00%)	<0.05
	2	50 (22.73%)	33 (30.00%)	17 (15.45%)	
	3	68 (30.91%)	30 (27.27%)	38 (34.55%)	
	4	47 (21.36%)	17 (15.45%)	30 (27.27%)	
	5	30 (13.64%)	16 (14.55%)	14 (12.73%)	
Group particip	1	22 (10.00%)	15 (13.63%)	7 (6.36%)	<0.05
	2	49 (22.27%)	30 (27.27%)	19 (17.27%)	
	3	74 (33.64%)	38 (34.55%)	36 (32.73%)	
	4	52 (23.64%)	16 (14.55%)	36 (32.73%)	
	5	23 (10.45%)	11 (10.00%)	12 (10.91%)	
Used online res	1	23 (10.45%)	15 (13.63%)	8 (7.27%)	<0.05
	2	51 (23.18%)	31 (28.18%)	20 (18.18%)	
	3	77 (35.00%)	39 (35.45%)	38 (34.55%)	
	4	43 (19.55%)	15 (13.63%)	28 (25.45%)	
	5	26 (11.82%)	10 (9.09%)	16 (14.55%)	
Moral gain	1	28 (12.73%)	17 (15.45%)	11 (10.00%)	<0.05
	2	46 (20.91%)	30 (27.27%)	16 (14.55%)	
	3	79 (35.91%)	39 (35.45%)	40 (36.36%)	
	4	41 (18.64%)	15 (13.63%)	26 (23.64%)	
	5	26 (11.82%)	9 (8.19%)	17 (15.45%)	
Moral identity	1	25 (11.36%)	15 (13.63%)	10 (9.09%)	<0.05

(Continued)

TABLE 3 (Continued)

Characteristic	Score	Total	Traditional teaching group	Civic and political integration teaching group	*P*
	2	40 (18.18%)	28 (25.45%)	12 (10.91%)	
	3	79 (35.91%)	38 (34.55%)	41 (37.27%)	
	4	47 (21.36%)	16 (14.55%)	31 (28.18%)	
	5	29 (13.18%)	13 (11.82%)	16 (14.55%)	
Total points			31.22 ± 4.40	35.38 ± 4.22	<0.01

TABLE 4 Multiple linear regression.

Characteristic	Coef	Std err	*t*	p	95% CI
Const	75.38	1.65	45.65	<0.01	(72.12, 78.63)
Learn commitment	−0.09	0.20	−0.43	0.668	(−0.48, 0.31)
Focus class	0.18	0.19	0.95	0.344	(−0.20, 0.56)
Review notes	0.30	0.20	1.50	0.134	(−0.09, 0.70)
Self learning	0.07	0.19	0.36	0.717	(−0.31, 0.45)
Course interest	0.25	0.20	1.30	0.197	(−0.13, 0.64)
Course rewarding	0.54	0.19	2.79	<0.01	(0.16, 0.92)
Group particip	0.44	0.21	2.11	<0.05	(0.03, 0.84)
Peer interaction	0.27	0.20	1.35	0.179	(−0.13, 0.67)
Used online res	0.46	0.21	2.22	<0.05	(0.05, 0.87)
Moral gain	0.52	0.20	2.57	<0.05	(0.12, 0.92)
Moral identity	−0.14	0.20	−0.69	0.491	(−0.53, 0.26)
Gender	0.46	0.46	0.98	0.319	(−0.44, 1.36)
Is prevent major	0.97	0.46	2.12	<0.05	(0.07, 1.88)

value-oriented dimensions contribute more strongly to student performance than do habitual study behaviors (Table 4).

3.5 Model development and interpretation

The global interpretation illustrates the overall feature importance of the model. As shown in the SHAP summary plots (Figures 1A–C), feature contributions to the model were evaluated based on the average SHAP values and are presented in descending order.

Additionally, local explanations analyze how specific predictions are generated for individual cases by integrating personalized input data (Figure 2).

Figure 3 illustrates the individual trajectories of the model's predictions for students' "composite quality scores," with each line representing a sample from the prediction process.

4 Discussion

Employing empirical research, the study aims to evaluate the effectiveness of CIPE-based blended teaching in improving students' academic achievement, moral identity, and professional values, and to identify the key learning behavior variables influencing this process. The findings are intended to provide both a theoretical foundation and a practical pathway for the deep integration of CIPE into medical education curricula.

4.1 Impact of CIPE integration on students' academic performance

In this study, students in the CIPE integration group scored significantly higher in overall quality (83.90 ± 3.08) compared to those in the traditional teaching group (82.66 ± 4.28) (Table 2). Furthermore, the CIPE group outperformed the traditional group across nine key dimensions: commitment to learning, classroom concentration, note review, course interest, learning motivation, group participation, use of online resources, ethical gains, and ethical identity (Table 3). These findings are consistent with previous research, suggesting that the integration of civic and political education into medical and public health curricula may enhance students' academic performance while reinforcing their professional commitment and ethical responsibility (Shen et al., 2025). This outcome corresponds, to some extent, with the dual

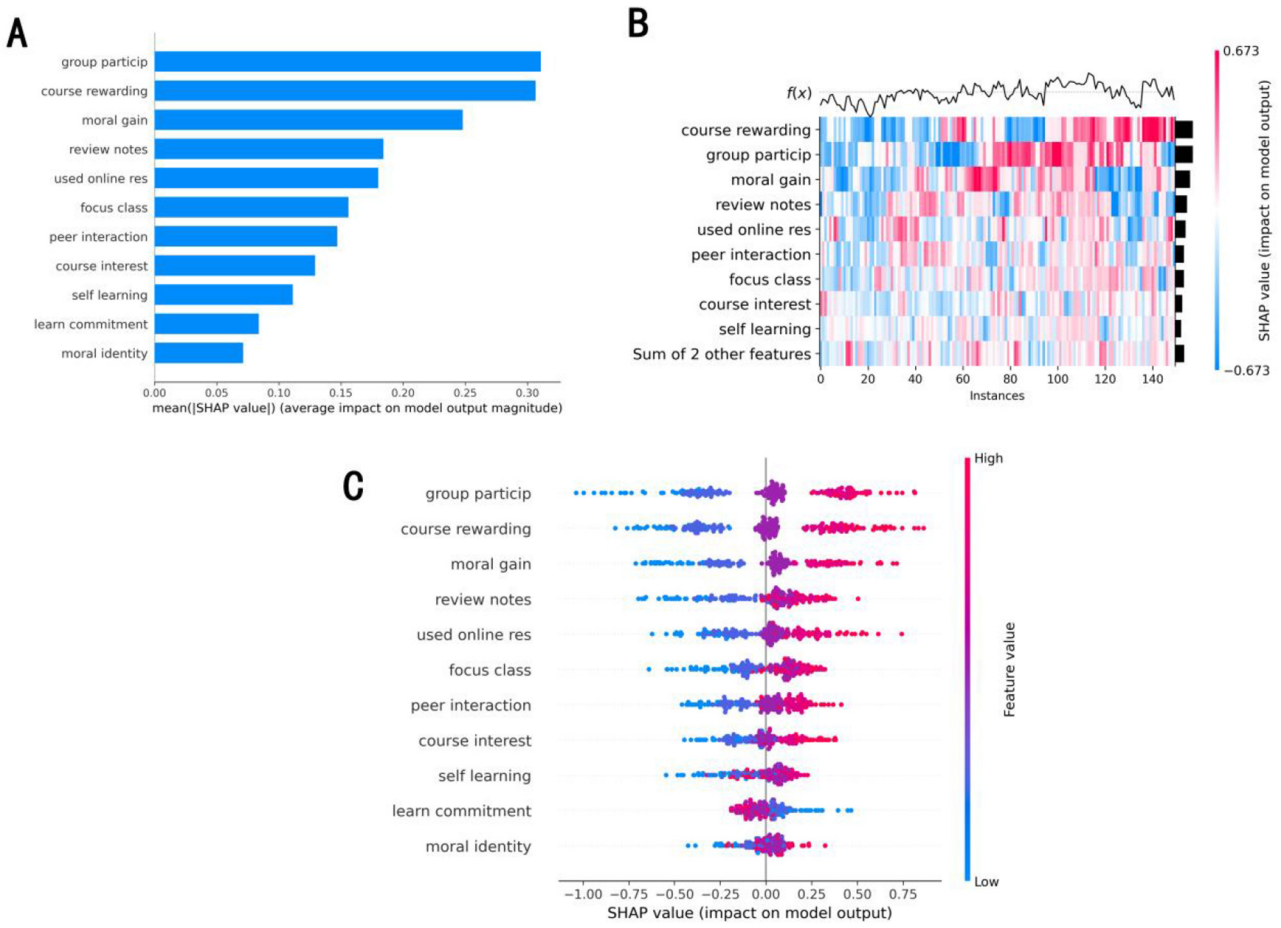

FIGURE 1
(A) and **(B)** show the top four features—group participation, course rewarding, moral gain, and review notes—ranked in descending order based on their mean absolute SHAP values. In **(B)**, color intensity reflects the magnitude of the SHAP values, with darker shades indicating higher absolute values and thus a greater impact on the model. The upper section displays the SVR model's predictions corresponding to these feature values. **(C)** Presents violin plots illustrating the distribution of SHAP values across different levels of each feature. Higher absolute SHAP values indicate stronger influence on the SVR model's predictions. Red dots denote higher feature values, while blue dots indicate lower values. Notably, higher scores in group participation, course rewarding, moral gain, and review notes are associated with increased contributions to the composite score.

educational objectives of "knowledge transmission and value guidance" (Sun et al., 2024).

4.2 Analysis of key predictors of student achievement and behavioral patterns

Multiple linear regression analysis revealed that course motivation, group participation, use of online resources, and ethical gains were significant positive predictors of students' composite scores (Table 4). Further global interpretation using SHAP confirmed the importance of these variables, with group participation, course motivation, ethical gains, and note review ranking among the top four in mean absolute SHAP values (Figures 1A–C), highlighting their critical roles in the model's predictive performance. In terms of learning strategies, although "note review" did not reach statistical significance in the regression model, its SHAP value indicated a meaningful contribution to model prediction, suggesting that some students possessed strong independent learning abilities. However, variations in the use of learning strategies remain evident, and it is recommended that instructors provide more targeted support and guidance for out-of-class learning. This aligns with the model proposed by Krishnasamy et al., which integrates autonomous learning with contextual support (Krishnasamy et al., 2022). In terms of affective engagement, "course motivation" demonstrated strong performance in both the regression model and SHAP rankings, suggesting that career-oriented and relevant content can effectively enhance student motivation, course appeal, and engagement (Chiencharoenthanakij et al., 2024). In terms of interaction and cooperation, "group participation" emerged as a key factor in the model, indicating that collaborative learning may play an important role in both knowledge acquisition and the internalization of values (Kibtiyah et al., 2025). However, individual differences in students' initiative toward interactive participation were evident, suggesting that instructors should adopt differentiated strategies to enhance the overall quality of classroom interaction. In terms of resource

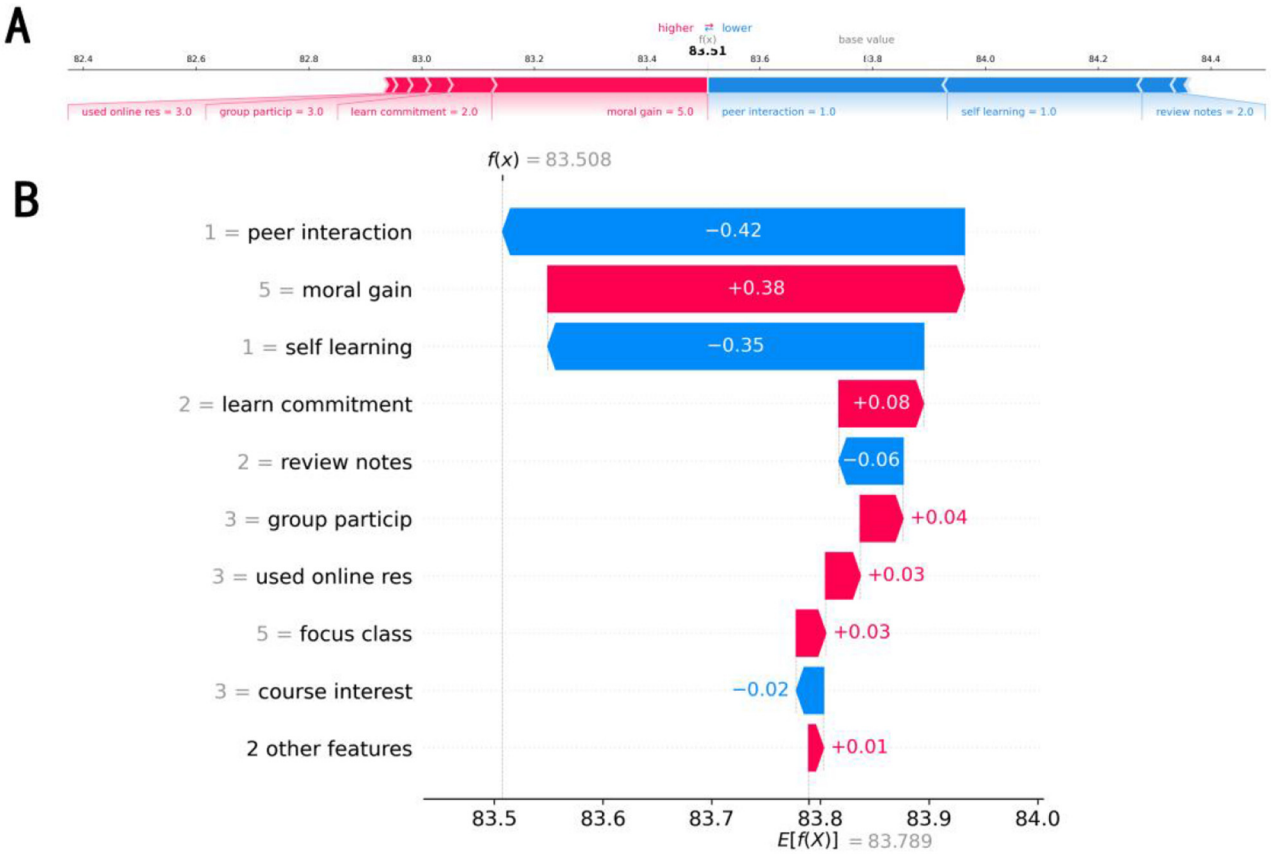

FIGURE 2
(A) Presents a force diagram where red bars represent features that increase the predicted values, and blue bars denote features that decrease the predicted values. The effects of different predictors vary significantly among individuals. **(B)** Displays a waterfall plot illustrating the stepwise contribution of each feature to individual predictions, with course rewarding identified as the most influential variable in the model.

utilization, "use of online resources" showed a significant positive correlation in the model, suggesting that it may be a key predictor of overall learning effectiveness. This suggests that the effective use of digital learning tools (e.g., micro-teaching, SPOCs) can substantially improve students' learning efficiency. However, partial SHAP interpretation (Figures 2, 3) also indicates that some students remain passive in utilizing these resources, highlighting the need to strengthen contextual guidance and foster greater initiative in resource engagement during instruction. In terms of value guidance, "moral gain" demonstrated strong explanatory power in both regression and SHAP analyses, suggesting that they may play an important role in the development of students' professional responsibility. Although "moral identity" was not statistically significant, its SHAP value exhibited a positive trend, suggesting that the integration of Civic Education into the curriculum has begun to yield positive outcomes in value cultivation.

4.3 The value of interpretable machine learning in educational evaluation

This study integrates SVR modeling with SHAP analysis to not only identify the key features most influential on composite scores but also to visualize their performance across individual students through student-level interpretability (Figures 2A, B). Force and waterfall plots clearly illustrate the differences in group participation, course motivation, and ethical gains between high- and low-scoring students. Additionally, the SHAP decision plot (Figure 3) visualizes the cumulative contribution trajectory of each feature from the model baseline to the final predicted value, effectively revealing individual differences in learning behaviors and value orientations. Compared to traditional statistical methods, interpretable machine learning not only provides insights into overall predictive trends but also enables precise, individualized interpretation. This offers robust data support for instructors to implement personalized interventions and feedback, thereby expanding both the depth and breadth of educational assessment.

4.4 Benefits and value of CIPE inclusion

The deep integration of CIPE into the OHOM course has demonstrated several educational benefits. First, it effectively promotes the systematic development of learning strategies, particularly behaviors such as note review and active resource consultation. Second, it strengthens the vocational orientation

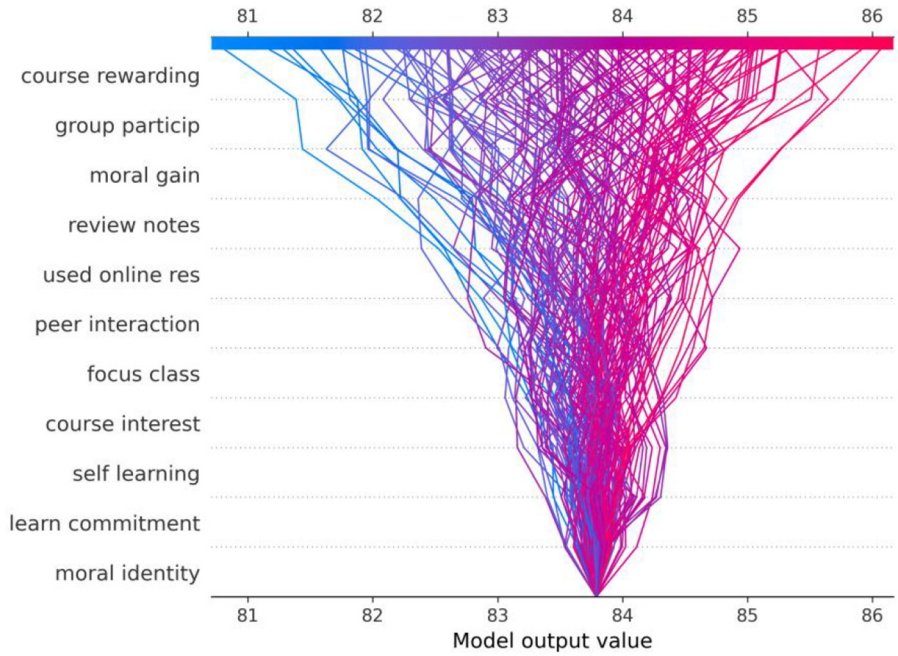

FIGURE 3
The horizontal axis represents the model's predicted output (i.e., the change in the composite score), while the vertical axis displays the top representative features, ranked from top to bottom according to their average impact on the model output.Each line originates from the baseline value on the left, sequentially incorporates the influence of the SHAP values for each feature, and ultimately reaches the model's predicted outcome for the individual. The dashed points along the curve indicate how the specific value of each feature for an individual influences the predicted value, either increasing or decreasing it. The color of the line indicates the magnitude of the predicted value: dark blue lines correspond to students with lower scores, while dark red lines correspond to students with higher scores. Feature colors indicate their influence on the direction of the model's predictions. This visualization elucidates how the model forecasts varying levels of aggregate performance based on individual differences in key characteristics.

and emotional appeal of the course content, thereby enhancing students' intrinsic motivation. Third, it fosters group interaction and peer collaboration, supporting the internalization of professional values. Fourth, it improves the efficient use of digital resources and facilitates the transition from passive reception to active construction in learning approaches. These findings suggest that the integration of CIPE may enhance students' academic performance and positively influence the cultivation of professional ethics and social responsibility, thereby demonstrating its potential practical value in medical education.

4.5 Limitations and future research directions

This study has several limitations that should be acknowledged. First, the use of convenience sampling with a relatively small sample size ($N = 220$) drawn from a single institution may have introduced selection bias and limits the representativeness and generalizability of the findings. Second, the cross-sectional design only allows for the identification of associations rather than causal inferences; future studies using longitudinal designs are needed to capture the dynamic development of students' academic performance and value formation. Third, the reliance on self-reported questionnaires, although reliability and validity tests were conducted, may still be subject to social desirability bias and recall bias, potentially affecting the objectivity of the responses. Fourth, for the purpose of maintaining interpretability in SHAP analysis, the dataset was not split into training and validation sets, which may have led to an overestimation of model generalizability. Finally, the study relied primarily on quantitative methods and lacked qualitative data, such as interviews or case studies, which could have provided deeper insights into students' subjective experiences of CIPE integration. Future research should adopt multi-center sampling, combine quantitative and qualitative approaches, and apply longitudinal designs with independent validation to strengthen the robustness and applicability of the conclusions.

5 Conclusion

This paper examines the feasibility of integrating CIPE into blended learning within the context of "Internet Plus," using the OHOM course as a platform. A six-dimensional assessment framework, developed with machine learning techniques (academic performance, classroom behavior, emotional engagement, resource utilization, and value alignment), indicated that students in the experimental group demonstrated more positive trends in learning participation, course interest, and awareness of professional ethics and social responsibility. Support Vector Regression (SVR) and SHAP analysis further suggested that CIPE-related factors may play a significant role in shaping learning

outcomes and values. Although these findings provide preliminary empirical support for the application of CIPE in medical education, the conclusions should be interpreted cautiously given the sample scope and research methodology. Practically, this study offers actionable insights and methodological references for advancing CIPE implementation in preventive medicine and related public health curricula.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ZZ: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. CK: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. CW: Data curation, Investigation, Resources, Writing – review & editing. YL: Methodology, Software, Writing – review & editing. YS: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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