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Development and Validation of a Process-Based Assessment System for E-Commerce Curricula: A Hybrid AHP--FCE Approach

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Abstract: This study proposes the Process-Based Assessment System (PBAS) tailored specifically for "theory-practice" integrated curricula, utilizing the E-commerce major in application-oriented universities as a comprehensive case study. As higher education increasingly emphasizes practical competencies alongside theoretical knowledge, traditional evaluation metrics often fall short in capturing the multifaceted nature of student development. To address this critical gap, the Analytic Hierarchy Process (AHP) is employed to systematically determine the precise weights of various evaluation indices, ensuring a balanced and objective assessment framework. Furthermore, the system's practical feasibility and educational impact are rigorously validated through extensive empirical evidence gathered from classroom implementations. The quantitative and qualitative results demonstrate that by seamlessly integrating observable student behaviors, interactive learning processes, and internal cognitive mechanisms, the PBAS successfully achieves both longitudinal tracking and transversal interaction throughout the entirety of the students' learning journey. This hierarchical, progressive, and highly dynamic evaluation model effectively reflects the continuous development of students' knowledge transfer capabilities. Moreover, it meticulously tracks nuanced learning behaviors, thereby significantly stimulating academic engagement and fostering a culture of autonomous, self-directed learning among students. Consequently, the proposed framework provides a robust, data-driven basis for continuous curriculum optimization through deep pedagogical reflection. Ultimately, the findings highlight that the PBAS demonstrates superior practical applicability, enhanced educational value, and greater scientific rigor when directly compared to conventional, outcome-focused assessment methods.

Keywords: process-based assessment; analytic hierarchy process; e-commerce education; instructional design; teaching evaluation; curriculum optimization

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1. Introduction

The Process-based Assessment system (PBAS) has emerged as an effective assessment model in contemporary higher education, with its applicability receiving escalating recognition across diverse curriculum evaluations of academic disciplines. Fundamentally, the PBAS aligns with the principles of formative assessment (FA). Both assessment types emphasize providing continuous feedback during the learning process to support students' progress and to make adjustments to instructional strategies, instead of relying solely on summative assessment. Formative assessment is portrayed as a mechanism for continuous feedback that enhances student learning through ongoing teacher-learner interaction and instructional adjustments [1]. Hence, the central tenet of formative assessment for learning as a powerful catalyst for meaningful pedagogical improvement retains substantial theoretical and empirical influence. In this context, the PBAS, as an extension evaluation method of formative assessment, is attracting growing attention from educational researchers and practitioners.

Existing studies provide a theoretical and practical foundation for understanding the necessity of formative assessment in teaching. Yet, the systematic application of formative assessment within E-commerce curricula, particularly in "theory-practice" integrated curricula, remains hampered by two primary challenges [2]. Firstly, the widespread use of AI in education introduces significant risks of "assessment distortion." With the prevalence of AI-driven tools, students increasingly rely on generative technologies to complete assignments and learning tasks, such as data analysis and solution design. This phenomenon blurs the boundaries of a student's authentic performance, making it difficult for instructors to discern whether the submitted work reflects the student's actual mastery of knowledge or merely an AI-generated output. Consequently, traditional outcome-oriented assessment faces a "black box" challenge: it can measure the quality of the final product but fails to verify the student's independent logical thinking, original innovation, and practical adaptability during the creation process. Secondly, the structural deficiencies of traditional assessment systems become pronounced in "theory-practice" integrated courses. An over-reliance on summative assessments, such as final examinations and single project reports, embodies a focus solely on outcomes at the expense of process. This assessment approach dampens self-learning motivation, reduces deep engagement for students, and widens the gap between instructional goals and actual learning experiences. This lagging, one-dimensional assessment approach is ill-suited to gauge dynamic learning development, such as incremental knowledge construction, continual skill enhancement, professional thinking, and collaborative practice, as well as to reflect students' learning progress. Consequently, there is an urgent need to design an assessment system that can track students' knowledge internalization, skill application, and teamwork, among other competencies, in real time. This would enable instructors to identify learning barriers early, optimize instructional design, and support students' comprehensive development.

Based on this context, this study develops a Process-Based Assessment system (PBAS) aligned with formative evaluation principles, specifically targeted at the E-commerce curriculum. It integrates core indicators, including knowledge mastery, student engagement, collaborative learning and communication, and students' self-learning ability. At the same time, this assessment method utilizes the Analytic Hierarchy Process (AHP) to scientifically allocate weights [3]. Hence, the paper aims to establish an assessment system to track students' learning paths, thereby creating a systematic assessment method for the learning process. Through this innovative assessment methodology, it enables real-time monitoring and dynamic regulation of students' learning behaviors, effectively overcoming the static constraints of conventional assessment models while advancing the digital transformation of the teaching assessment system. Furthermore, this assessment method can provide precise feedback on the results of students' learning activities, thereby refining teaching intervention strategies for the instructor and improving student learning outcomes.

2. Theoretical Perspectives and Implementation for FA and PBAS

There are varying interpretations among education scholars regarding the differences and complementarities between the connotations of the FA and the PBAS and their application value for teaching evaluation.

The theoretical concepts of the FA can be traced back to the proposal on how to adjust teaching paths based on classroom feedback results to ensure the achievement of teaching goals and ultimately promote the continuous development of students. The FA refers to the ongoing collection and analysis of students' learning feedback during instruction, with timely adjustments to teaching strategies and learning methods to foster students' learning progression. In the practice of teaching, the FA emphasizes gathering feedback at key instructional milestones in order to diagnose learners' outcomes and identify challenging areas. This form of assessment helps students identify stage-wise learning difficulties at each stage and track their learning development trajectories. By leveraging data from periodic assessments and classroom performance, it supports teachers in refining subsequent instructional designs. Consequently, this approach enables traceable adjustments to teaching strategies and timely guidance in learning methods to students, thereby sustaining continuous student development [3].

Despite the unparalleled advantages of the FA in the existing educational evaluation system, this assessment still has some weaknesses. The weakness of the FA form reflects in the lack of effective evaluation tools, which leads to a tendency for superficial implementation in the practical teaching assessment process. In this condition, this assessment keeps the cognitive level in the phases of shallow learning for students, making it difficult to reach higher levels of thinking development and achieve teaching objectives related to cultivating emotional attitudes [3].

Specifically, the tendency toward superficial implementation induced by the lack of effective evaluation tools is reflected in several aspects. First, the FA lacks an ongoing and systematic approach, resulting in an incomplete process. This problem is driven by significant variability in outcomes when implementation is determined solely by phased results. In essence, this fragmented assessment data makes it impossible to establish a complete assessment path covering the entire teaching process. The second concern is that the FA suffers from the inadequacy of its reliance on students' self-regulated learning. More precisely, the FA feedback is significantly more effective for students possessing high self-regulated learning skills; conversely, FA implementation struggles to effectively motivate or facilitate learning for students with low levels of self-regulated learning. It can be seen that the effectiveness of FA is limited. Given this limitation, and in contexts where students' self-learning investment is insufficient, educators should adopt assessment approaches that are highly targeted and motivating. The third tendency toward superficial implementation is the fragmentation of the FA feedback, which undermines the authenticity and comprehensiveness of its diagnostic function. The FA tends to provide immediate evaluations tied to specific stages, and its fragmented feedback makes it difficult to effectively capture students' complete learning trajectories or the dynamic development of knowledge and skills. This leads to the evaluation feedback losing its diagnostic function. In addition, the non-continuous feedback by FA is insufficient to effectively foster the development of students' self-regulated learning abilities. In this condition, instructors also struggle to discern students' deeper learning obstacles or to uncover their developmental potential from these isolated assessment fragments, resulting in teaching improvements that lack targeted relevance [4]. Finally, the FA assessment exhibits two fundamental complementary weaknesses in practice. On the one hand, its application often demonstrates a tendency to rely on a limited set of qualitative assessment paths. Consequently, this approach leads to the neglect of rich, quantitative evidence regarding the learning process for students. On the other hand, this evaluation system fails to trace the longitudinal effects of instructional feedback, which severs the crucial link between momentary interventions and the nurturing of enduring competencies. As a result, this weakness hinders the practical implementation of lifelong learning.

Theoretical Perspectives on PBAS: In contrast to the limitations of FA identified previously, the PBAS emphasizes continuous monitoring of the learning process and dynamic adjustment mechanisms, which can effectively compensate for the limitations of the FA in covering the entire teaching cycle and achieving sustained impact [5]. A systematic literature review indicated that current studies to deepen the PBAS in teaching practice can be categorized into three major perspectives as follows:

The PBAS carries a dual empowerment in the "teaching-learning process" and provides real-time evidence to monitor and guide instruction, while also fostering students' self-reflection and adjustment of learning strategies. These functions help optimize the instructional process and enhance learning effects. Course teaching assessment in higher education should emphasize learning process-based observation, integrating it organically into the assessment process to help instructors diagnose students' learning results. This approach not only reflects the essential significance of evaluation for students' knowledge acquisition but also plays a crucial role in fostering students' self-directed learning abilities and promoting learner autonomy. This form of assessment application can drive the initiative of self-study and benefit students by fostering independent thinking and problem-solving capabilities. The PBAS highlights its evaluative function by offering feedback to help students identify learning weaknesses promptly and implement improvements. At the same time, it can drive the development of students' self-regulation ability and the realization of high-quality learning goals. The diverse array of PBAS assessment tools reflects the comprehensiveness and adaptability of this approach. From the perspective of learning ability, early studies have shown that the PBAS is essentially a measure that runs throughout the entire teaching activity, aiming to diagnose students' engagement and motivation in learning. The assessment of learning ability should not be limited to the evaluation of the final results of learning but should also track the thinking and cognitive processes of students in the learning process [6]. This marks a significant shift in the focus of assessment from "learning outcomes" to "the learning process." Given this principle, researchers have continuously optimized and refined the technical approaches for developing the PBAS indicators to achieve refined tracking and evaluation of the cognitive learning process. As a result, students' learning logs, interactive discussions, self-reflection, peer assessments, project analyses, and platform data can comprehensively capture learners' attitudes, behaviors, and learning outcomes. Hence, this perspective indicates that process-oriented assessment is both holistic and developmental within the teaching process.

From the literature review on the FA and the PBAS, it is evident that these two important teaching assessment approaches differ in their theoretical bases, purposes, and implementation methods. Yet, both are committed to promoting students' holistic development and improving teaching quality. FA focuses on providing feedback regarding learners' progress at various stages of the learning process [7]. The learning outcomes are typically gathered at each stage in instructional activities to make formative judgments and adjust subsequent instructional strategies. The PBAS emphasizes the continuous observation of learning dynamics throughout the entire teaching process, tracking students' cognitive development trajectories by capturing real-time data of the learning process. It should be noted, however, that despite the PBAS being progressively recognized as one of the key pedagogical diagnostic approaches for enhancing curriculum and instructional quality, it is still significantly constrained by systemic deficiencies and data fragmentation in its current implementation. Consequently, this structural weakness makes it challenging to fully capture students' learning trajectories and effectively cultivate self-regulated learning across diverse cohorts, thereby undermining the significance of its application as a teaching diagnostic approach. Thus, it is necessary to establish a closed-loop evaluative system that integrates the entire cycle of teaching diagnosis, feedback, improvement, and learning within the "theory-practice integrated" curriculum.

3. Construction of the PBAS Indicator System

A systematic review of the existing literature provides a research framework for the construction of the PBAS in this paper. This assessment system framework, grounded in the context of the "theory-practice integrated" curriculum, integrates existing teaching assessment tools to establish a dynamic learning monitoring and instant feedback evaluative mechanism. By continuously optimizing students' learning pathways, it facilitates the PBAS and iterative improvement of learning behaviors, attitudes, and academic achievements throughout the entire teaching cycle, thereby expanding the practical application of teaching evaluation in higher education. The PBAS is realized as a developmental evaluation model that spans the entire instructional process, characterized by its dynamic and evolutionary nature. The core of this evaluative approach lies in the systematic, continuous focus on, and multi-dimensional, dynamic evaluation of the student learning process. Grounded in an E-commerce Data Analysis course's objectives and design, and informed by teaching reflections, this study developed an assessment framework for process assessment, pedagogical diagnosis, and instructional approaches, specifically designed for practice-oriented courses [8].

As Table 1 shows, this framework adopts learning engagement and reflection on teaching as the central elements of the PBAS. It is designed to track and assess the lifelong learning development trajectory of students, including their acquisition of cognition, application comprehension, classroom participation, learning communication, and self-exploration throughout the entire knowledge construction process. This tracking enables the dynamic diagnosis and precise regulation of the effects of instructional interventions [9].

Table 1. The PBAS evaluation indicator system

Layer A (Goal Layer)	**Layer B (Criterion Layer)**	**Layer C (Sub-criterion Layer)**
Indicator System for PBAS	Primary Indicators	Sub-indicators
	B1. Mastery of Knowledge Objectives	C1.1 Conceptual Comprehension C1.2. Application & Transfer of Knowledge
	B2. Student Engagement	C2.1 Classroom Performance &Active Participation C2.2. Quality & Frequency of Teacher-Student Interaction C2.3 Cognitive Innovation & Higher-Order Thinking
	B3. Collaborative Learning &Communication	C3.1 Effective Teamwork Skills C3.2 Individual Accountability C3.3 Frequency of Collaborative discussion
	B4. Self- Learning Skills	C4.1 Goal Setting & Learning Planning C4.2 Information Literacy & Research Skills C4.3 Critical Analysis & Evaluation of Information

3.1. Primary Indicators: The Theoretical Dimensions

The framework of this assessment indicator system uses four primary evaluative indicators: "Mastery of Knowledge Objective, Student Engagement, Collaborative Learning and Communication, Self-Learning Skills." This structure aligns with the main dimensions of learning sciences: "Cognitive, Affective, Social, and Meta-Cognitive," and dynamically tracks the relationship between instructional input and learning outcomes [10]. By leveraging multi-dimensional observation points, it provides real-time evidence to support instructional assessment, ensuring the internal logical consistency of the assessment indicators framework. The eleven sub-indicators focus on the operational and implementation aspects of assessment. These sub-indicators have been meticulously refined and extended into several observable points of the acquisition process, forming a three-dimensional evaluation framework: "Abstract Construct, Behavioral Indicator, Quantitative Record."

3.1.1. Mastery of Knowledge Objectives-(B1)

This assessment dimension emphasizes "Conceptual Understanding" and "Knowledge Application" as primary observation points to assess the trajectory of students' cognitive depth. Specifically, "Conceptual Understanding" focuses on the attainment of Near Transfer, evaluating the structured mastery and accurate discrimination of core concepts within analogous pedagogical contexts. Conversely, "Knowledge Application" is directed toward the realization of Far Transfer, examining the efficacy with which students transcend contextual boundaries to transform acquired knowledge into the capacity for resolving unstructured, complex problems [11]. Knowledge transfer serves not only as the foundation for practice but also as the bedrock for cultivating innovative thinking and high-order cognitive faculties (Transfer-based Mastery). By validating theoretical models within authentic pedagogical contexts, this evaluative framework reinforces the quality of knowledge internalization and constructs a bidirectional reinforcing bridge between "theoretical acquisition" and "practical output."

3.1.2. Student Engagement-(B2)

Student engagement is conceptualized as a multidimensional construct encompassing both affective and behavioral psychological states [12]. Research indicates that evaluating self-efficacy is fundamental to learning, as it serves as a core driver of student effort. Within the teaching process, a three-tiered hierarchical tracking system comprising "attendance rates, interaction frequency, and innovative questioning" is employed to systematically monitor students' persistence, sense of belonging, and emotional investment in learning tasks. This evaluative design is specifically intended to capture the procedural characteristics of "value evaluation," utilizing behavioral observations as a proxy to reflect the depth and quality of a student's cognitive and professional engagement.

3.1.3. Collaborative Learning & Communication (B3)

This indicator reflects the constructivist essence of modern pedagogy. Collaborative learning is not merely a process of knowledge construction but an essential vehicle for fostering professional literacy. By structuring role allocation based on collaborative communication and member engagement, as well as facilitating interactive discussions, students are provided with opportunities for reflection throughout their learning process. This enhances their problem identification skills and promotes continuous optimization in subsequent learning phases. Simultaneously, this approach fosters the internalization of self-responsibility and communication efficacy by immersing students in team collaborations that simulate professional environments. By examining the "rationality of division of labor, frequency of mutual assistance, and results of peer evaluation," the dynamic evolution of team cognition can be characterized, with a specific focus on measuring the distributed regulation efficiency of cognitive load among members [13]. This approach not only evaluates current collaborative performance but also aims to imperceptibly cultivate the sense of responsibility and communication competence indispensable for future professional roles.

3.1.4. Self-Learning Skills (B4)

Student agency in managing the learning process is a critical indicator of the sophistication of metacognitive regulation and a central manifestation of the importance of self-regulated learning. However, learning motivation is not a stable trait but a complex, dynamic process; due to a lack of effective monitoring of motivational trajectories, existing pedagogical assessments often fail to foster sustained learning behaviors. Genuine learning proficiency depends not only on intellectual capacity but, more crucially, on a student's ability to manage and regulate their own motivation over a longitudinal period [4]. By quantifying the rationality and efficacy of dimensions such as "Goal Setting & Learning Planning, Information Literacy & Research Skills, and Information Literacy & Research Skills," a seamless transition from theoretical constructs to observable variables can be achieved. The core objective is to facilitate a shift from passive reception to active exploration, thereby enhancing students' adaptability to future professional roles.

3.2. Sub-Indicators: Operationalization and Quantifiability

These eleven secondary indicators (sub-indicators) serve as fundamental observation points linking primary indicators to their corresponding operational definitions. Each secondary indicator is derived from its respective primary indicator, functioning as a diagnostic tool to ensure the validity and reliability of the assessment.

3.2.1. Mastery of Knowledge Objectives (B1)

Conceptual Comprehension: This observation utilizes near-transfer tasks as a context to evaluate students' ability to identify and apply related conceptual understanding within familiar learning knowledge [14].

Application and Transfer of Knowledge: Focused on far-transfer attainment, this diagnostic indicator examines the effectiveness with which students reconstruct abstract theoretical principles and creatively apply the resulting abstracted knowledge in diverse, unstructured, and complex real-world contexts [15].

3.2.2. Student Engagement (B2)

Classroom performance and active participation focus on students' multidimensional investment in the learning process [16]. This observation evaluates students' comprehension of knowledge.

The quality and frequency of teacher-student interaction are measured by the depth and relevance of dialogic exchanges. This assesses students' ability to analyze knowledge insights while developing their communication skills.

Cognitive innovation and higher-order thinking are assessed through observable evidence of complex intellectual engagement. This tracks students' ability to draw unconventional connections between concepts, generate novel questions or solutions, and demonstrate critical or metacognitive reflection in their reasoning [17].

3.2.3. Collaborative Learning & Communication (B3)

Effective Teamwork Skills: This observation point is characterized by the seamless integration of students' role-based collaboration and the logical organization of the collective workflow [1].

Individual Accountability: Measured by the proportion of an individual's identifiable contribution to the overall group output, ensuring transparency and evaluation of personal effort within collaborative tasks [18].

Frequency of Collaborative Discussion: Evaluated based on the distributed regulation of cognitive load as a key criterion [19]. It enhances students' knowledge and understanding through the intensity of peer feedback and mutual knowledge construction during team activities.

3.2.4. Self-Learning Skills (B4)

Goal Setting & Learning Planning: This indicator emphasizes cultivating students' self-learning skills by encouraging them to establish actionable goals and learning plans. It evaluates and promotes students' self-regulatory growth through the quality of initial plans and subsequent reflective adjustments documented in progress records.

Information Literacy & Research Skills: This observation point assesses students' precision in seeking and applying information during independent exploration. It aims to enhance and develop their ability to actively pursue knowledge.

Critical Analysis & Evaluation of Information: Building on the previous indicator, this observation evaluates students' depth of critical reflection, focusing on training their ability to discern insights by assessing the relevance and validity of information [20].

This assessment indicator system integrates longitudinal tracking with horizontal interaction, embedding observable behaviors, interactive acquisition processes, and internal cognitive mechanisms within a unified evaluative framework [21]. It establishes a coherent and progressively structured dynamic system that provides actionable pathways for personalized learning support while laying the foundation for a theoretically robust and practically implementable evaluation system for precise instructional reflection and decision-making.

4. Weight Allocation and Consistency Verification

4.1. Construction of the Judgment Matrix for Primary Indicators

To ensure the rigor and scientific basis of this evaluation system, this study applies the Analytic Hierarchy Process (AHP) to determine the weights of the Primary Indicators from the Criterion layer. Accordingly, four professors and associate professors from different disciplines across universities were invited to form an evaluation panel. Using Saaty's 1–9 scale, the panel conducted pairwise comparisons to assess the relative importance of the primary indicators. Based on these expert judgments, a pairwise comparison matrix for the criterion layer was constructed (see Table 2).

Table 2. Pairwise Comparison Matrix for the Criterion Layer (B)

A	(B1) Mastery of Knowledge Objectives	(B2) Student Engagement	(B3) Collaborative Learning & Communication	(B4) Self-Learning Skills
B1	1	1/2	1/3	4/3
B2	2	1	2/3	2
B3	3	3/2	1	3
B4	3/4	1/2	1/3	1

As shown in Table 3, a fourth-order pairwise comparison matrix was constructed for the primary indicators: Mastery of Knowledge Objectives (B1), Student Engagement (B2), Collaborative Learning & Communication (B3), and Self-Learning Skills (B4). Using the AHP method, the resulting eigenvector is [0.616, 1.140, 1.711, 0.533] respectively. The resulting weights for the four primary indicators are: 15.392% for B1, 28.511% for B2, 42.767% for B3, and 13.330% for B4. Based on the eigenvectors, the maximum eigenvalue was determined to be 4.010, with a corresponding Consistency Index (CI) of 0.003. Given that the Random Index (RI) for a 4th-order matrix is 0.89, the Consistency Ratio (CR) was calculated as follows: CR = CI(0.003)/RI(0.89) = 0.0034. Since the CR value (0.0034) is significantly less than 0.1, it satisfies Saaty's consistency criterion. This indicates that the primary indicator judgment matrix is logically consistent, and the weights are deemed valid for further analysis [22].

Table 3. Analysis Results of Primary Indicators

Primary Indicators	Eigenvector	Weight	Maximum Eigenvalue(λmax)	CI
(B1)Mastery of Knowledge Objectives	0.616	15.3920%	4.010	0.003
(B2) Student Engagement	1.140	28.5113%		
(B3) Collaborative Learning & Communication	1.711	42.7670%		
(B4) Self- Learning Skills	0.533	13.3297%		

4.2. Determining Sub-Indicator Weights for the PBAS

Based on the established indicator system for the PBAS, 11 sub-indicators (C1.1 to C4.3) within the Sub-criterion Layer were analyzed [23]. Pairwise comparison matrices were constructed for each sub-criterion group to conduct consistency testing. The results are as follows:

4.2.1. Weight Analysis for Sub-Indicators under B1

According to the matrix in Table 4, the relative importance of "Application & Transfer of Knowledge (C1.2)" compared to "Conceptual Comprehension (C1.1)" is 2:1. This indicates that in the evaluation of B1 (Mastery of Knowledge Objectives), "Knowledge Application" is regarded as more critical, supporting the emphasis of the PBAS on cultivating students' ability to transfer knowledge during the learning process. Concurrently, Table 5 illustrates that the weights for C1.2 and C1.1 are 66.67% and 33.33%, respectively. Since the judgment matrix for B1 is a second-order matrix, it inherently satisfies the consistency requirement with a CI value of 0.000. This reflects that the evaluation system prioritizes the ability to apply and transfer knowledge [24]. These findings suggest that sub-indicators C1.1 and C1.2 are suitable for tracking and evaluating students' capacity development during the knowledge transfer phase of the PBAS.

Table 4. Pairwise Comparison Matrix for Sub-indicators of B1

	C1.1 Conceptual Comprehension	C1.2 Application & Transfer of Knowledge
C1.1Conceptual Comprehension	1	1/2
C1.2 Application & Transfer of Knowledge	2	1

Table 5. Analysis Results of Sub-indicators under B1

	Eigenvector	Weight	Maximum Eigenvalue(λmax)	CI
C1.1.Conceptual Comprehension	0.667	33.33%	2.000	0.000
C1.2 .Application & Transfer of Knowledge	1.333	66.67%		

4.2.2. Weight Analysis for Sub-Indicators under B2

The pairwise comparison matrix in Table 6 reveals the relative importance of the sub-indicators within Student Engagement (B2): Classroom Performance & Active Participation (C2.1), Quality & Frequency of Teacher-Student Interaction (C2.2), and Cognitive Innovation & Higher-Order Thinking (C2.3). Among these, C2.3 occupies a central position in B2. Its importance ratio relative to C2.1 is 4:1 (scale value of 4), and 2:1 relative to C2.2 (scale value of 2), highlighting the leading significance of innovative capacity. The importance of the C2.2 indicator is three times that of C2.1 (scale value of 3), suggesting that the quality of interaction is pivotal for stimulating cognitive engagement. Meanwhile, C2.1 serves as the baseline (scale value of 1), reflecting its supportive role as a fundamental form of participation.

Table 6. Pairwise Comparison Matrix for Sub-indicators of B2

	C2.1 Classroom Performance & Active Participation	**C2.2 Quality& Frequency of Teacher-Student Interaction**	**C2.3. Cognitive Innovation &Higher-Order Thinking**
C2.1ClassroomPerformance & Active Participation	1	1/3	1/4
C2.2 .Quality & Frequency of Teacher-Student Interaction	3	1	1/2
C2.3.Cognitive Innovation & Higher-Order Thinking	4	2	1

The analysis results in Table 7 further validate the expert judgments. C2.3 emerges as the core priority with a dominant weight of 55.7%, confirming its high importance in the assessment. The weight of C2.2 (32.0%) is significantly higher than that of C2.1 (12.3%), approximately 2.6 times greater. The consistency test was successfully passed with CR=CI(0.005)/RI(0.58)=0.0086<0.1, indicating a high level of consensus among the evaluation panel regarding the progressive relationship of "Classroom Performance, Teacher-Student Interaction, Cognitive Innovation & Higher-Order Thinking."

Table 7. Analysis Results of Sub-indicators under B2

	Eigenvector	**Weight**	**Maximum Eigenvalue(λmax)**	**CI**
C2.1 Classroom Performance &Active Participation	0.123	12.3%	3.010	0.005
C2.2. Quality & Frequency of Teacher-Student Interaction	0.320	32.0%		
C2.3.Cognitive Innovation & Higher-Order Thinking	0.557	55.7%		

In summary, the data from this sub-criterion layer demonstrate that the PBAS Indicator System establishes a stepped evaluation path: C2.1 ensures the breadth of student participation, C2.2 enhances the depth, and C2.3 directs the height of engagement. This provides a theoretical anchor for shifting the PBAS from "behavioral recording" toward "cognitive development," enabling the transition from quantitative to qualitative value in practical applications.

4.2.3. Weight Analysis for Sub-Indicators under B3

The pairwise comparison matrix in Table 8 quantifies the relative importance of the sub-indicators within Collaborative Learning & Communication (B3): Effective Teamwork Skills (C3.1), Individual Accountability (C3.2), and Frequency of Collaborative Discussion (C3.3). Specifically, C3.1 is judged to be three times as important as C3.2 (scale value of 3) and five times as important as C3.3 (scale value of 5). Meanwhile, C3.2 is assigned three times the importance of C3.3.

Table 8. Pairwise Comparison Matrix for Sub-indicators of B3

	C3.1 Effective Teamwork Skills	**C3.2 Individual Accountability**	**C3.3 Frequency Collaborative discussion**
C3.1Effective Teamwork Skills	1	3	5
C3.2Individual Accountability	1/3	1	3
C3.3 Frequency of Collaborative discussion	1/5	1/3	1

The AHP analysis results presented in Table 9 show that C3.1 carries a dominant weight of 63.33%, followed by C3.2 at 26.05% and C3.3 at 10.62%. According to the consistency test, the Consistency Index (CI) is 0.019, and the corresponding Random Index (RI) for a third-order matrix is 0.580. The calculated Consistency Ratio is CR=CI/RI=0.0328<0.1. This calculated result indicates that the matrix successfully passes the consistency test.

Table 9. Analysis Results of Sub-indicators under B3

	Eigenvector	**Weight**	**Maximum Eigenvalue(λmax)**	**CI**
C3.1 Effective Teamwork Skills	1.900	63.33%	3.039	0.019
C3.2 Individual Accountability	0.781	26.05%		
C3.3 Frequency of Collaborative discussion	0.318	10.62%		

These results (CR=0.0328) signify a high degree of alignment between expert judgments and the original research design [24]. Effective teamwork skills hold a significantly dominant position in the evaluation of collaborative learning, followed by individual accountability, while discussion frequency serves as a fundamental supporting dimension. This provides a rigorous and applicable quantitative basis for observing the primary indicator of "Collaborative Learning & Communication."

4.2.4. Weight Analysis for Sub-Indicators under B4

The pairwise comparison matrix for the Sub-criterion Layer of B4 is presented in Table 10. Through the AHP pairwise comparison method, the relative importance of the three sub-indicators under Self-Learning Skills (B4), namely "Goal Setting & Learning Planning (C4.1), Information Literacy & Research Skills (C4.2), and Critical Analysis & Evaluation of Information (C4.3)," has been quantified [17]. This matrix reflects the expert panel's judgments: C4.2 is assigned the highest priority (with its relative importance significantly higher than that of C4.1 and C4.3), followed by C4.3, while C4.1 is considered the baseline support to self-learning for students.

Table 10. Pairwise Comparison Matrix for Sub-indicators of B4

	C4.1 Goal Setting & Learning Planning	**C4.2 Information Literacy & Research Skills**	**C4.3 Critical Analysis & Evaluation of Information**
C4.1 Goal Setting & Learning Planning	1	1/3	1/2
C4.2 Information Literacy & Research Skills	3	1	2
C4.3 Critical Analysis & Evaluation of Information	2	1/2	1

According to the analysis results of the Sub-criterion Layer for B4 shown in Table 11, C4.2 occupies a dominant position with a weight of 53.90% (eigenvector of 1.617), highlighting its core role in autonomous learning capacity. C4.3 provides secondary support with a weight of 29.73% (eigenvector of 0.892), while the weight of C4.1 is notably lower at 16.38% (eigenvector of 0.491), confirming its foundational orientation [23, 24]. This validates the importance hierarchy of "C4.2 > C4.3 > C4.1" within the judgment matrix, emphasizing the significance of the "acquisition process." Furthermore, the Consistency Index (CI) is 0.005, and the corresponding standard Random Index (RI) is 0.580. The calculated Consistency Ratio is CR=CI/RI=0.0086<0.1, indicating that the consistency test has been successfully passed. Consequently, these data systematically reveal the hierarchical weight structure and the logical reliability of the sub-indicators for self-learning skills.

Table 11. Analysis Results of Sub-indicators under B4

	Eigenvector	**Weight**	**Maximum Eigenvalue(λmax)**	**CI**
C4.1 Goal Setting & Learning Planning	0.491	16.38%	3.009	0.005
C4.2 Information Literacy & Research Skills	1.617	53.90%		
C4.3 Critical Analysis & Evaluation of Information	0.892	29.73%		

5. Application Verification for the PBAS Indicator System

To verify the feasibility and operability of the constructed evaluation system in section 3, this study conducted a pilot application within the "Business Data Analysis" course for E-commerce majors. The verification process was implemented in three stages. First, at the beginning of the semester, the PBAS was integrated into the curriculum by embedding specific observation points of each sub-indicator into various project tasks. Students were required to complete these tasks throughout the semester to ensure deep engagement with the assessment criteria. Subsequently, at the end of the semester, a questionnaire survey was conducted to gain student feedback, resulting in a total of 56 valid questionnaires collected from two representative classes. This sample size is considered appropriate for a pilot study, focusing on students' perceptions of the comprehensibility, clarity, and operability of the indicators and their corresponding tasks to verify practical applicability. Finally, the collected data were analyzed using the Fuzzy Comprehensive Evaluation (FCE) method to validate the suitability of the indicators. The evaluation set was defined as Verification Level 5: $V=\{v_1,v_2,v_3,v_4,v_5\}$, corresponding to the five-point Likert scale adopted in the questionnaire (see Table 12): 1 point (Strongly Disagree/Inapplicable), 2 points (Disagree), 3 points (Neutral), 4 points (Agree), and 5 points (Strongly Agree/Applicable).

Table 12. Distribution of Degrees for Each Indicator(Percentage of Feedback)

Primary Indicators	Sub-indicators	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
B1. Mastery of Knowledge Objectives	C1.1 Conceptual Comprehension	0.00%	0.00%	16.07%	53.57%	30.36%
	C1.2. Application & Transfer of Knowledge	0.00%	3.57%	3.57%	60.71%	32.14%
B2. Student Engagement	C2.1 Classroom Performance & Active Participation	0.00%	0.00%	16.07%	44.64%	39.29%
	C2.2 Quality & Frequency of Teacher-Student Interaction	0.00%	0.00%	16.07%	46.43%	37.50%
	C2.3Cognitive Innovation & Higher-Order Thinking	0.00%	1.79%	8.93%	48.21%	41.07%
B3. Collaborative Learning &Communication	C3.1 Effective Teamwork Skills	0.00%	0.00%	18.75%	51.79%	29.46%
	C3.2 Individual Accountability	0.00%	0.00%	10.71%	50.00%	39.29%
	C3.3 Frequency of Collaborative discussion	0.00%	0.00%	12.50%	42.86%	44.64%
B4. Self-Learning Skills	C4.1GoalSetting & Learning Planning	0.00%	1.79%	19.64%	48.21%	28.57%
	C4.2 Information Literacy & Research Skills	0.00%	5.36%	16.07%	51.79%	26.79%
	C4.3 Critical Analysis & Evaluation of Information	0.00%	0.00%	19.64%	51.79%	28.57%

5.1. Construction of Matrices for Primary Indicators

Based on the data results from Table 12, the fuzzy relationship matrices (R1 to R4) for each primary indicator were established. Each row in these matrices represents the membership degree of the corresponding sub-indicators across the evaluation set "V."

Mastery of Knowledge Objectives (R1):

$$R_1 = \begin{bmatrix} 0.000 & 0.000 & 0.1607 & 0.5357 & 0.3036 \\ 0.000 & 0.0357 & 0.0357 & 0.6071 & 0.3214 \end{bmatrix}$$

Student Engagement (R2):

$$R_2 = \begin{bmatrix} 0.000 & 0.000 & 0.1607 & 0.4464 & 0.3929 \\ 0.000 & 0.000 & 0.1607 & 0.4643 & 0.3750 \\ 0.000 & 0.0179 & 0.0893 & 0.4821 & 0.4107 \end{bmatrix}$$

Collaborative Learning & Communication (R3):

$$R_3 = \begin{bmatrix} 0.000 & 0.000 & 0.1875 & 0.5179 & 0.2946 \\ 0.000 & 0.000 & 0.1071 & 0.5000 & 0.3929 \\ 0.000 & 0.000 & 0.1250 & 0.4286 & 0.4464 \end{bmatrix}$$

Self-Learning Skills (R4):

$$R_4 = \begin{bmatrix} 0.000 & 0.000 & 0.1964 & 0.4821 & 0.2857 \\ 0.000 & 0.0536 & 0.1607 & 0.5179 & 0.2679 \\ 0.000 & 0.000 & 0.1964 & 0.5179 & 0.2857 \end{bmatrix}$$

5.2. Weight Sets of Indicators Based on AHP

According to the AHP analysis results from Table 3 to Table 11, the weight sets for both primary and sub-indicators are determined as follows:

The weight set of Primary Indicators (W):

W=[0.1539,0.2851,0.4276,0.1332]

Weight sets of Sub-indicators for each primary indicator (Wi):

- Mastery of Knowledge Objectives (W_1): W_1=[0.33,0.66]
- Student Engagement (W_2): W_2=[0.123,0.320 , 0.557]
- Collaborative Learning & Communication (W_3): W_3=[0.633,0.260,0.106]
- Self-Learning Skills (W_4): W_4=[0.163,0.529,0.297]

5.3. Analysis and Results:

Based on the formula Bi=Wi · Ri, the composite evaluation vectors for the sub-indicators under each primary indicator were calculated as follows:

$B_1=W_1 \cdot R_1 = [0.0000 \quad 0.0238 \quad 0.0774 \quad 0.5833 \quad 0.3155]$

$B_2=W_2 \cdot R_2 = [0.0000 \quad 0.0010 \quad 0.1209 \quad 0.4720 \quad 0.3971]$

$B_3=W_3 \cdot R_3 = [0.0000 \quad 0.0000 \quad 0.1599 \quad 0.5038 \quad 0.3363]$

$B_4=W_4 \cdot R_4 = [0.0000 \quad 0.0286 \quad 0.1785 \quad 0.5148 \quad 0.2782]$

By taking these secondary evaluation vectors (Bi) as rows, the total fuzzy relationship matrix (R) for the primary indicators was established as follows:

$$R=\begin{bmatrix} 0.0000 & 0.0238 & 0.0774 & 0.5833 & 0.3155 \\ 0.0000 & 0.0010 & 0.1209 & 0.4720 & 0.3971 \\ 0.0000 & 0.0000 & 0.1599 & 0.5038 & 0.3363 \\ 0.0000 & 0.0286 & 0.1785 & 0.5148 & 0.2782 \end{bmatrix}$$

By aggregating these vectors, the total fuzzy relationship matrix (R) for the primary indicators was established [4]. Finally, using the model B=W · R, the final comprehensive evaluation vector was obtained:

$B=W \cdot R = [0.0000 \quad 0.0078 \quad 0.1386 \quad 0.5083 \quad 0.3427]$

The final result B indicates that the membership degrees for 'Agree' (0.5083) and 'Strongly Agree' (0.3427) are dominant. The cumulative membership for these two positive levels reaches 85.1%, which statistically validates that the proposed PBA indicator system is highly effective and well-received by students.

6. Discussion & Implications

6.1. Principal Findings and Theoretical Contributions

The comprehensive validation and analysis results indicate a significantly positive trend in students' attitudes toward the implementation of the PBA (Process-Based Assessment) in this practical course. Specifically, no students selected "Strongly Disagree" (0.0%), and only 0.78% chose "Disagree," reflecting a high level of overall acceptance among the student body. Meanwhile, 13.86% of respondents maintained a "Neutral" stance, representing a cautious but non-negative position. Notably, 50.83% of the participating students "Agreed," while 34.27% "Strongly Agreed," further demonstrating widespread support for this assessment framework.

From the perspective of the primary indicators (B1--B4) in the criterion layer, all vectors exhibit a significant right-skewed distribution, indicating the excellent overall performance of the evaluation system. Among the sub-indicators, the total proportion of negative feedback (Strongly Disagree + Disagree) remained below 2.86%, with B2 (Student Engagement) reaching a minimum of only 0.10%. This suggests that none of the primary indicators possess significant defects. Furthermore, neutral evaluations ranged between 7.74% and 17.85%. It is noteworthy that the neutral rate for B4 (Self-Learning Skills, 17.85%) is 2.31 times that of B1 (Mastery of Knowledge Objectives, 7.74%), highlighting that students perceive the mastery of explicit knowledge (learning objectives) more rapidly, while their perception of implicit skill improvement (self-learning ability) is more reserved. Nevertheless, the positive rating for B4 remained robust at 79.30%, while B1 reached 89.88%.

In summary, the experimental results and positive student feedback preliminarily validate the effectiveness of the PBA system, proving its high applicability and credibility as an assessment tool [5].

6.2. Practical Implications

The progressive structure established through the Analytic Hierarchy Process (AHP) represents not only a hierarchical division of pedagogical evaluation but also a cognitive advancement path for students from "theoretical acquisition" to "innovation cultivation." This model of longitudinal tracking and horizontal interaction organically integrates observable behaviors with internal cognitive mechanisms, enabling dynamic monitoring of the entire learning process. The progressive structure clearly reflects the transition from knowledge transfer in theoretical acquisition and skill application to the development of complex problem-solving abilities, eventually guiding students toward self-learning and innovative capacity. Quantitative data from observational indicators intuitively reflect trends in cognitive hierarchy during the "learning and practicing" process, showing significant improvement over traditional assessment models. Consequently, by integrating cross-level indicators, the PBAS establishes a dynamically following evaluation paradigm that stimulates student engagement and provides an effective basis for pedagogical reflection and real-time course optimization [2].

7. Conclusion, Limitations, Future Research

7.1. Conclusion

Process-based assessment anchors its core connotation to the holistic tracking of "how learners learn." This dynamic evaluation focuses on achieving pedagogical goals by first capturing and defining the boundaries of the student's Zone of Proximal Development (ZPD) while recording trajectories of emotional engagement and cognitive activity, and second, taking the learning process as the orientation to stimulate student initiative through multi-dimensional evaluation. This approach fosters continuous development within the cycles of active participation, self-evaluation, peer assessment, and teacher-student interaction.

Given the implicit obstacles in e-commerce practical courses, such as disciplinary complexity, limited class hours, and traditional assessment constraints, this study constructed a tailored process-oriented assessment system. Aimed at the process of acquisition, the system emphasizes the self-expression of learning behaviors and social emotions to achieve "thinking visualization." By building a three-dimensional framework of "process constructs → acquisition behavior indicators → quantitative records," a dynamic evaluation paradigm was formed, promoting the shift from surface learning to deep learning.

7.2. Limitations and Future Research

While the PBAS effectively promotes active learning, certain limitations remain that require further refinement in future work. First, regarding the long-term validation of learning effectiveness: as this study focused on verifying the validity and applicability of the system, the direct impact of this model on students' long-term learning outcomes requires further longitudinal tracking. Second, the optimization of the assessment burden on instructors: the evaluation process demands significant time investment, as analyzing complex indicator data is labor-intensive. Therefore, subsequent research will focus on exploring the application of Artificial Intelligence (AI) technologies within this framework. By introducing automated behavior tracking and intelligent feedback algorithms, we aim to reduce the burden on teachers and enhance evaluation efficiency, thereby strengthening the precision and real-time responsiveness of the assessment system. Third, the limitations in disciplinary and curricular applicability: while the underlying evaluation logic of this study possesses a degree of universality, the specific indicators were developed based on the "theory-practice" curriculum of the E-commerce major. Consequently, there may be limitations when applying this assessment system to purely theoretical courses in other disciplines where practical observation points are less prominent. Future research could further explore the compatibility and adjustment strategies of this evaluation model across diverse disciplinary attributes.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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