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Competency-Based Education Design for Workforce Training: Framework and Application

Chao Chen [1,*]

[1] Beijing Mingxuetang Education Technology Co., Ltd., Beijing, China
* Correspondence: Chao Chen, Beijing Mingxuetang Education Technology Co., Ltd., Beijing, China

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Abstract: To construct an education and training system adaptable to job task structures, this study employs capability element analysis, task chain modeling, and modular content configuration to investigate the operational mechanisms of training objective alignment, process control, and quality monitoring. Using multi-scenario training deployment as an example, it quantitatively measures capability enhancement and management efficiency improvements. Results indicate that the system enables precise generation of training paths through parametric configuration, demonstrating significant optimization in operational stability, resource scheduling efficiency, and service consistency.

Keywords: job competency; modular training; process control; quality monitoring; competency measurement

1. Introduction

The accelerated evolution of job structures and the increasing digitization of operational scenarios render traditional experiential training models inadequate for supporting the refined enhancement of competency requirements. The intensifying coupling between competency elements, task workflows, and operational environments compels training systems to shift from knowledge transfer toward competency generation centered on job tasks. In many operational domains, fragmented instructional practices, inconsistent assessment standards, and limited traceability of competency progression further widen the gap between training outputs and practical job demands, highlighting the urgency of adopting structured training methodologies. Consequently, a training framework must be established to map job task chains, identify competency gaps, and support precise resource allocation. Through structured modeling of task nodes, competency items, and instructional modules, a computable and traceable training mechanism is formed [1]. The research scope encompasses training needs analysis, system architecture design, implementation methodologies, and process quality control. By integrating simulation-based assessment, multi-source behavioral data, and standardized module coding, the framework enhances the interoperability of training components and supports iterative refinement across instruction, monitoring, and evaluation layers. It introduces parametric modeling, modular structures, and data-driven processes to achieve end-to-end integration. Expected outcomes include advancing the technical, structured, and quantifiable development of training activities in content design, operational organization, and effectiveness evaluation, thereby establishing a methodological foundation for continuous job competency enhancement.

2. Job Competency-Oriented Educational Training Needs Analysis

Identifying training needs for competency-oriented positions must closely align with the management task chain of educational service roles, focusing on analyzing capability gaps demonstrated by educational institutions in critical scenarios such as enrollment organization, curriculum system operation, resource allocation, and service quality assurance [2]. As an enterprise deeply engaged in educational technology services, Beijing Mingxuetang Education Technology Co., Ltd. provides practical cases showing that competency gaps often emerge from inconsistencies between operational processes, decision-making complexity, and service delivery requirements across diverse training environments. Compared to single teaching positions, educational training management roles involve greater complexity in decision-making levels, collaborative scope, and responsibility boundaries. Their competency requirements extend beyond educational expertise and policy comprehension to encompass integrated management capabilities such as organizational coordination, process design, project oversight, and risk management. With the rapid expansion of non-degree education, vocational training, and lifelong learning programs across diverse settings, educational management roles have evolved beyond traditional administrative tasks to encompass market development, service optimization, and systematic operations. This shift demands greater precision and coherence in training systems. Against this backdrop, continuously collecting and analyzing metrics such as enrollment performance, course delivery quality, service response efficiency, and management decision effectiveness can transform management capability gaps into quantifiable, benchmarkable training needs. This provides practical evidence and directional guidance for building a modular training system tailored to educational management roles.

3. Overall Design of the Competency-Based Education and Training System

3.1. Training Objectives and Competency Benchmarking Mechanism

The training objectives and competency benchmarking mechanism constructs a competency matrix based on job task decomposition. By mapping task steps to knowledge, skill, and operational behavior indicators, it establishes quantifiable benchmarking relationships for course configuration. The benchmarking process employs a weighted scoring model with parameterized settings for the importance of different competency items. The calculation formula is:

$$M = \frac{\sum_{i=1}^{n} w_i s_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

Where M represents the job competency alignment score, w_i denotes the weight of competency item i (derived from task criticality and operational risk coefficient), s_i indicates the competency achievement score (quantified from scenario-based task assessment results), and n is the total number of competency items. To enhance reliability, the weighting parameters are calibrated through iterative validation against historical task performance data, and sensitivity analysis is conducted to ensure the model remains stable under variations in scenario difficulty or assessment noise. In application, the system design uses job operation workflows as input. It compares each competency item against task nodes to generate a competency gap matrix. Based on the sub-values of M, training objectives are then refined into modular competency units [3]. The system structure employs a three-tier mapping approach: "Task Node Library-Competency Item Library-Course Module Library." Dynamic consistency checks ensure that changes in task parameters, equipment configurations, or competency evaluation rules automatically trigger updates in associated modules, maintaining the robustness of the benchmarking chain under evolving operational requirements. Through parameter binding, it achieves automated benchmarking output to drive course selection, training scenario construction, and resource orchestration.

3.2. Pathway for Modularizing Training Content

The modular construction of training content centers on the job task chain, breaking down knowledge points, skill actions, and operational scenarios into granular components that can be individually linked to competency items. During this decomposition, content is categorized based on task step prerequisites, equipment parameters, operational instructions, and quality assessment points into three types: foundational knowledge modules, critical skill modules, and scenario-based operation modules. To support precise orchestration, each module is digitized into structured metadata fields, enabling traceability of prerequisite logic, resource dependencies, and behavioral indicators across the entire task chain. Dependencies are established according to task execution sequences [4]. Within each module, materials are organized using the "operational elements-process control-abnormal handling" structure, forming independently deployable instructional units. A module coding system establishes bidirectional links between modules and competency matrices, enabling the system to automatically assemble content sequences based on task nodes when retrieving training plans. Each module is configured with corresponding practical difficulty levels, equipment specifications, and resource package version numbers, facilitating rapid adaptation and deployment across diverse training scenarios. To ensure consistent cross-scenario reuse, modules incorporate versioned parameter sets and scenario-specific constraint mappings, allowing the system to dynamically adjust instructional pathways as equipment models or operational conditions change. After decomposing training content into three module categories-knowledge, skills, and scenarios-standardized combinations and process-oriented configurations can be achieved according to the structure shown in Figure 1.

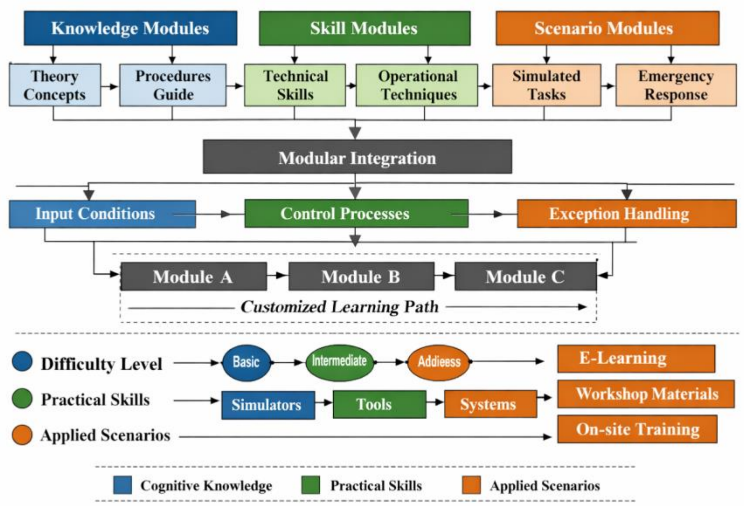

Figure 1. Modular Structure of Training Content.

3.3. Training Operation and Management Support System

The training operation and management support system centers on a task-driven training process. By embedding data collection nodes in planning, implementation, and monitoring phases, it enables real-time recording of trainee behavior, resource utilization, and equipment load [5]. These nodes capture multi-granular behavioral features, equipment state variables, and environmental conditions at configurable sampling frequencies, allowing the system to fuse heterogeneous data streams into coherent operational profiles for subsequent analysis. The operational end employs a chained control approach of "training scheduling-resource allocation-process monitoring." The scheduling module automatically generates training sequences based on role competency gaps. The resource allocation module performs automated matching considering equipment utilization rates, scenario configuration parameters, and instructor schedules. The process monitoring module continuously samples operational trajectories, step timestamps, and anomaly trigger points. The platform side configures a modular resource library that synchronizes updates with the competency item coding system, enabling on-demand loading of scenario tasks, simulation scripts, and operating procedures. The management end establishes training log indexes and performance data caches, supporting retrieval by task nodes, module IDs, and equipment parameters. To support sustained operational stability, the platform incorporates dynamic resource scaling, script version management, and exception recovery mechanisms, ensuring that data pipelines and task execution workflows remain consistent even under fluctuating workloads or partial component failures. This provides structured data for subsequent debriefing and process tracking. By constructing a three-tier support structure-"Process Control-Resource Management-Data Services"-the platform ensures stable and traceable training operations.

4. Position-Competency-Oriented Training Implementation Methodology

4.1. Instructional Organization and Training Process Design

Instructional organization and training process design are structured around job task sequences, linking instructional units through operational scenarios. The front end of the process uses competency gap matrices as input, automatically generating training paths that integrate knowledge points, skill actions, and field tasks. The generation logic incorporates scenario complexity levels, equipment availability constraints, and individual learning progression patterns, enabling the system to adapt task difficulty and resource allocation in real time while preserving alignment with job requirements. Each node is bound to a specific resource package version, equipment model, and operational environment parameters. Classroom organization follows a linear structure of "Explanation → Demonstration → Scenario Operation → Debriefing." Before entering the scenario operation phase, the system pushes step prompts and safety verification items to ensure operational conditions meet equipment requirements. During process execution, all critical actions are recorded via sensors or simulation terminals, capturing timestamps, motion trajectories, and operational deviation values. The system triggers corrective prompts based on preset thresholds. Upon training completion, the system automatically initiates a debriefing process. It aggregates trainee step durations, deviation records, and anomaly trigger points by task node, generating structured training logs for subsequent competency assessment and path adjustment. These data streams are further used to recalibrate task node weights, refine step-level guidance, and update module dependencies, allowing subsequent training cycles to evolve toward higher precision and personalized instructional pathways. The overall workflow organization uses task node numbers as a unified index, enabling precise alignment between teaching activities, resource invocations, and monitoring data. This ensures controllability and traceability throughout the training process.

4.2. Instructor Allocation and Resource Integration Methods

Instructor allocation and resource integration are indexed by job task chains, with instructor roles determined by matching competency items to teaching activities. During configuration, the system automatically retrieves instructor resources capable of delivering instruction, monitoring, or demonstrations for each teaching unit based on task node skill levels, equipment operation complexity, and scenario script requirements. The instructor database maintains multidimensional capability profiles, including certification levels, equipment operation histories, assessment outcomes, and scenario-specific performance records, allowing the system to update role suitability scores dynamically as new training data accumulate. Priority is assigned according to instructors' skill certification levels, equipment authorization scopes, and scheduling parameters. For cross-scenario tasks, the platform employs a "lead instructor + skills coach + on-site monitor" configuration to ensure parallel execution of knowledge delivery, skill training, and safety oversight without conflicts. Resource integration utilizes a three-dimensional matrix ("equipment type - module requirement - usage period") to centrally schedule simulation terminals, tools, training stations, and facilities, preventing resource conflicts or underutilization. Prior to training commencement, the system binds equipment parameters (e.g., rated load, travel range, motion thresholds) to corresponding task scripts and performs preemptive availability verification. To further stabilize resource orchestration, the system incorporates conflict resolution strategies, load-balancing rules, and bidirectional consistency checks between equipment data and script parameters, enabling automated adjustments when environmental or operational discrepancies occur. During task execution, instructors can monitor trainees' operation logs, equipment status, and risk alerts in real-time via monitoring terminals, enabling data-driven immediate intervention and process guidance. The specific implementation path for instructor allocation and resource integration follows the structured scheduling and role assignment process illustrated in Figure 2.

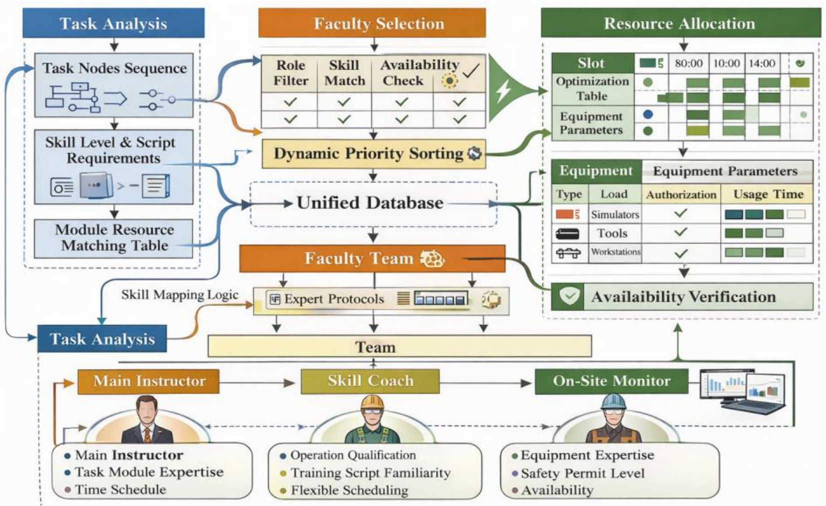

Figure 2. Instructor Configuration and Resource Integration Flowchart.

4.3. Training Process Quality Control Mechanism

The training process quality control mechanism operates through a four-stage chain: "data collection → metric calculation → threshold determination → corrective action execution." The system deploys motion sensors, step timestamp recorders, and anomaly trigger monitoring units at task nodes to perform real-time sampling of operational trajectory deviations, step durations, and risk trigger points. Quality control indices are calculated using a weighted model:

$$Q = \alpha T + \beta D + \gamma E \tag{2}$$

Where: Q represents the process quality index; T denotes the time deviation component (normalized difference between actual and standard duration); D indicates the action deviation component (quantified via trajectory deviation curve integration);E represents the anomaly trigger frequency term; α, β, γ denote system-defined weighting coefficients. To improve robustness, the system applies smoothing filters to suppress sensor noise and uses sliding-window aggregation to stabilize deviation trends, ensuring that transient fluctuations do not trigger premature corrective actions. The system updates Q in real-time during execution. When any component or the composite value reaches the threshold range, corrective logic is automatically triggered, including action prompts, step replay, or script downgrade. Scenario-aware dynamic thresholds are further applied to accommodate differences in equipment precision, trainee proficiency, and task complexity, while fallback recovery logic ensures task continuity in the event of data loss or abnormal sensor behavior. The control module and task database employ a bidirectional binding structure, enabling quality data traceability by node ID and supporting automatic adjustment of subsequent training paths.

5. Application and Effectiveness Evaluation of the Training System

5.1. Application Scenarios and Implementation Conditions Analysis

Deployment of the training system across diverse operational scenarios requires customized configurations based on job structure, equipment conditions, and work organization methods. For centralized production scenarios, training relies on fixed workstations and standardized equipment parameters. The system binds scenarios based on workstation IDs, equipment models, and task scripts, ensuring one-to-one correspondence between training processes and on-site conditions. To maintain operational fidelity, the system performs consistency checks between task-chain requirements and workstation capability profiles, automatically flagging mismatches in cycle time, tool availability, or operational tolerances before scenario activation. For multi-region collaborative operations, the system must integrate cross-regional resource scheduling modules. By synchronously validating conditions such as equipment availability, instructor scheduling, and network bandwidth, it ensures seamless loading of training scripts in remote environments. In high-risk operation scenarios, sensor density and safety threshold configurations must be enhanced. This creates an augmented training environment by expanding motion capture precision and enabling real-time monitoring of environmental indicators (e.g., temperature, vibration, pressure).To further stabilize execution in heterogeneous environments, the system incorporates hybrid simulation-field calibration, dynamic threshold adaptation, and fallback task routing to address latency fluctuations, sensor faults, or equipment inconsistencies across sites. After scenario deployment, the system dynamically configures equipment parameters and script versions based on task node complexity, ensuring training consistency and controllability across varying conditions. The adaptation of architectures to different training deployment environments can be planned and configured according to the scenario classification framework shown in Figure 3.

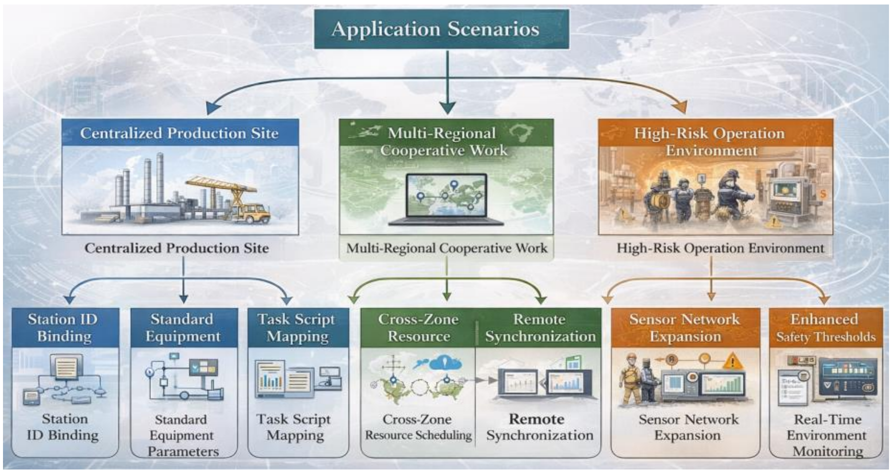

Figure 3. Application Scenario Classification Structure Diagram.

5.2. Measurement of Job Competency Enhancement

Quantitative comparisons of changes in trainees' key competency items can be performed using pre- and post-training assessment data from identical tasks. The system records step duration, motion deviation, and anomaly trigger events, then normalizes these into aligned data sequences. Key assessment results are shown in Table 1.

Table 1. Competency Improvement Assessment Data.

Competency Item ID	Assessment Metric	Pre-Training Value	Post-Training Value	Improvement Rate (%)
C-01	Average Step Duration (s)	18.4	12.7	31.0
C-02	Average motion deviation (mm)	6.2	3.1	50.0
C-03	Maximum Motion Trajectory Deviation (mm)	14.8	9.6	35.1
C-04	Abnormal Trigger Frequency (times/task)	3.0	1.0	66.7
C-05	Critical Node Completion Quality Score (0-100)	68	86	26.5
C-06	Total task duration (s)	145	102	29.7
C-07	Operational Stability Index (0-1)	0.42	0.71	69.0

Table 1 shows that all capability metrics exhibit a stable improvement trend post-training. Notably, the mean trajectory deviation and abnormal trigger frequency decreased most significantly, indicating quantifiable progress in trainees' operational precision and risk control. The increase in key node quality scores and operational stability index demonstrates enhanced overall task execution consistency and controllability. These evaluation results provide a basis for optimizing subsequent training pathways.

5.3. Management and Service Capability Improvement Outcomes

Throughout the training system's operational cycle, continuous sampling of key process indicators on both the management and service sides was conducted. This covered dimensions such as scheduling efficiency, resource response speed, and monitoring accuracy to identify performance bottlenecks and evaluate improvement effectiveness. Key monitoring results are summarized in Table 2.

Table 2. Management and Service Capability Metrics Statistics.

Indicator ID	Indicator Name	Period Start Value	Cycle End Value	Change Rate (%)
M-01	Average Scheduling Duration (ms)	420	280	33.3
M-02	Task Wait Duration (s)	12.6	7.4	41.3
M-03	Device Resource Utilization Conflict Rate (%)	8.2	3.1	62.2
S-01	Service Response Latency (ms)	185	96	48.1
S-02	Configuration Error Trigger Rate (times/week)	14	5	64.3
S-03	Monitoring alarm error rate (%)	6.5	2.7	58.5
S-04	Training Script Synchronization Failure Rate (%)	3.8	1.4	63.2

Table 2 shows that both the management-end scheduling computation time and task waiting time have decreased significantly, indicating smoother resource scheduling after parameter adjustments. The decline in resource occupancy conflict rate suggests a marked reduction in overlapping device scheduling. On the service side, response latency, configuration error trigger rate, and monitoring alert error rate all show downward trends, reflecting that the unified configuration and monitoring mechanisms have effectively enhanced system execution consistency. The improvement in script synchronization failure rate further reduces the risk of interruptions during the training process. Collectively, these metrics demonstrate significant optimization in operational management and service support capabilities, providing data-driven evidence for enhancing the scalable operational capacity of the training system in subsequent phases.

6. Conclusion

The competency-based training system, operating under a collaborative mechanism that integrates task chain analysis, competency quantification, and modular content development, has established a data-driven, process-oriented operational framework. This framework facilitates the transition of training activities from experience-based organization to structured configuration and process control. Its systematic architecture also enhances the portability of training models across heterogeneous organizational settings, enabling consistent execution standards and scalable deployment in industries with diverse operational requirements. Through continuous feedback on resource allocation parameters, critical node data, and quality control metrics, the system's operational segments establish a traceable, iterative competency generation chain. This ensures dynamic alignment between training objectives, content, and implementation processes. As application scenarios expand and operational data accumulates, there remains room for improvement in the precision of competency diagnostic models, the adaptability of training scripts, and the self-optimization capabilities of management links. Advances in predictive analytics, behavior-pattern mining, and cross-platform interoperability will further strengthen the system's ability to refine training pathways, stabilize resource orchestration, and support automated decision-making within complex operational ecosystems. Future development should focus on deepening the technical framework through intelligent scheduling, cross-regional collaborative training, and multi-source behavioral data integration. This will provide a more precise and scalable support structure for the dynamic growth of job competencies.

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