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Research on Virtual Simulation Scenario Development and Collaborative Rescue Training of Chemical Park Fires for Undergraduate Emergency Response Majors

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Abstract

Fire and explosion incidents in hazardous chemical industrial parks are characterized by their sudden onset, rapid progression, numerous secondary risks, and the need for high levels of interagency coordination. Traditional in-person drills and written contingency plans struggle to replicate complex incident scenarios in a low-risk, low-cost, and end-to-end manner. Taking the "August 12" Extraordinary Major Fire and Explosion Accident at the Port of Tianjin as a typical case study, this paper addresses issues in undergraduate emergency response practical training—such as a lack of diverse scenarios, imprecise alignment between theory and practice, and insufficient resource sharing—by developing a virtual simulation scenario for fires in hazardous chemical industrial parks and a multi-agency coordinated rescue drill plan. Based on a post-incident analysis of the case study, the research identifies key elements such as hazardous chemical types, park layout, fire and explosion progression, rescue routes, personnel evacuation, and environmental monitoring. Using 3ds Max and Unity 3D, the study visualizes three-dimensional scenes, dynamic fires, traffic congestion, and rescue operations; In accordance with the emergency response command procedures for hazardous chemical accidents, the study designed roles and tasks for emergency command, fire and rescue, medical aid, public security and traffic management, environmental monitoring, and technical support, forming a collaborative drill process comprising "alert reception and assessment—on-site reconnaissance—cordoning and evacuation—firefighting and search and rescue—medical and environmental response—termination and debriefing." Furthermore, this scenario was integrated into the "Four Categories, Five Levels, and 4R Phases" practical teaching framework, establishing a resource organization model tailored to course experiments, comprehensive design, professional skills training, and competition-based innovation. Research indicates that virtual simulation scenarios of fires in hazardous chemical industrial parks can effectively enhance the visualization of accident processes, the intuitiveness of contingency plan execution, and the effectiveness of multi-role collaborative training, and can serve as a model achievement in the development of virtual simulation-based practical teaching systems for undergraduate emergency response programs.

Keywords

Hazardous Chemicals Industrial Park, Virtual Reality, Fires and Explosions, Coordinated Rescue, Practical Instruction, Emergency Drill.

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1. Introduction

Hazardous chemicals industrial parks [1] serve as key hubs for the clustered development of the chemical industry, undertaking functions such as the production, storage, transshipment, and logistics services for hazardous chemicals. Due to the complex variety of flammable, explosive, highly toxic, and corrosive substances within these parks, the high density of facilities, and the intermingling of personnel, vehicles, and pipeline systems, a fire or explosion incident can very easily trigger secondary risks such as heat radiation, blast waves, the spread of toxic gases, traffic congestion, trapped personnel, and environmental pollution [2]. The “August 12” Ruihai Company hazardous materials warehouse fire and explosion incident at the Port of Tianjin clearly demonstrates that accidents in hazardous chemicals industrial parks are not merely issues of isolated fires or explosions, but rather systemic safety issues resulting from the combined effects of corporate accountability, park planning and layout, management of hazardous chemical inventories, emergency information sharing, and interagency coordination capabilities [3].

Traditional emergency drills for hazardous chemical incidents primarily rely on written contingency plans, tabletop exercises, and limited live drills. While this approach helps participants become familiar with basic procedures, it has significant shortcomings when dealing with major and particularly serious hazardous chemical fire and explosion incidents: First, it is difficult to realistically recreate high-risk scenarios; processes such as fire spread, chain reactions, and toxic gas dispersion are hard to fully simulate in a physical environment; Second, drills are costly and time-consuming to organize, making it difficult to support routine training; third, static written contingency plans lack spatial and dynamic representation, making it difficult for participants to quickly grasp the locations of hazard sources, road conditions, and the distribution of resources; fourth, interagency coordination often remains at the script level, with a lack of a recordable and evaluable data chain linking the issuance of orders, feedback on execution, consultation and adjustments, and post-drill debriefing and optimization.

Virtual reality technology offers a new approach to teaching and simulating fire incidents in hazardous chemical industrial parks [4]. Through 3D modeling, real-time rendering, particle effects, interactive triggers, and multi-user collaboration, it can recreate the entire process—from the onset of an incident to its progression and resolution—in a safe and controlled environment, allowing students or participants to engage in incident simulations from a first-person, command, or bird’s-eye view. Compared to traditional drills, VR drills offer advantages such as repeatability, the ability to pause and review, scalability, and low risk. They can transform the organizational structure, response procedures, resource allocation, and coordination relationships outlined in written contingency plans into visual tasks.

From the perspective of educational reform, fire and explosion scenarios in hazardous chemicals industrial parks also serve as vital resources for building a practical training system for undergraduate students in emergency response [5]. It is necessary to establish a “four-category, five-tier” practical training system for these students based on virtual scenarios of typical accidents and disasters, and to align the practical content with the various stages of the emergency response process, including pre-incident prevention and preparation [6], incident monitoring and early warning, in-incident rescue and response, and post-incident recovery and reconstruction. Fire scenarios in hazardous chemical industrial parks align precisely with the curriculum modules of Emergency Technology and Management, Emergency Management, Science and Engineering of Disaster Prevention and Mitigation, and Data Science and Big Data Technology, and can also support various competency levels, including basic training, course experiments, comprehensive design projects, professional skills training, and competition-based innovation [7-15].

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Based on this, this paper focuses on the process of “reviewing typical accident cases—constructing virtual scenarios—conducting multi-role collaborative drills—applying them to practical teaching—and providing evaluation and feedback.” The research not only examines the technical implementation of hazardous chemical accident rescue drills but also emphasizes their value as educational resources and their suitability for teaching as the final deliverable of an educational reform project .

2. Research Framework and Project Alignment

Based on the “August 12” Extraordinary Major Fire and Explosion Accident at the Port of Tianjin, this paper constructs a virtual simulation scenario of a fire in a hazardous chemicals industrial park. The research framework is shown in Figure 1. Guided by the objectives of the educational reform project, this framework integrates resources for typical accident scenarios, technical support from VR platforms, and the evaluation of educational applications. Specifically, the project aims to establish a repository of virtual scenarios and models for typical accidents and disasters; the scenario resources focus on fire and explosion incidents in hazardous chemical industrial parks; the platform relies on 3D modeling, Unity 3D, and virtual interaction; and the educational applications emphasize multi-role collaborative drills, course experiments, and evaluation feedback.

In terms of the “four-category” framework, fire scenarios in hazardous chemicals industrial parks can serve multiple academic disciplines simultaneously. For the Emergency Technology and Management program, these scenarios can be used for training in hazard identification, firefighting techniques, equipment deployment, and on-site response; for the Emergency Management major, the scenario can be used for contingency plan development, response activation, resource allocation, and interagency coordination; for the Disaster Prevention and Mitigation Science and Engineering major, the scenario can be used for accident chain analysis, regional risk assessment, and post-disaster recovery analysis; and for the Data Science and Big Data Technology (Emergency Information Technology) track, the scenario can be used for spatial data annotation, situational assessment, exercise data recording, and decision-support analysis.

Within the “five-level” framework, scenarios can serve as resources for accident recognition in basic training and as operational objects on the platform during course experiments; they can be used for developing drill scripts and optimizing processes in comprehensive design, as well as for job-specific drills in professional skills training; furthermore, they can support scenario expansion, model optimization, and the design of intelligent decision-making aids in competition-based innovation. Consequently, the virtual scenario of a fire in a hazardous chemicals industrial park is not an isolated graduation project outcome, but rather a representative resource that can be integrated into the overall practical framework of educational reform initiatives.

Within the 4R crisis management theory framework, the Reduction phase emphasizes risk mitigation, which corresponds to the identification of hazardous chemicals, hazard inspections, industrial park layout, and safety distance analysis; the Readiness phase emphasizes preparedness, which corresponds to emergency response plans, resource allocation, drill preparation, and personnel assignments; the Response phase emphasizes emergency response, which corresponds to alarm reception and assessment, on-site reconnaissance, cordoning off and evacuation, firefighting and rescue, and coordination between medical and environmental protection teams; The Recovery phase emphasizes recovery and improvement, corresponding to the termination of the emergency response, pollution assessment, post-incident review and summary, and optimization of emergency plans. The subsequent sections of this paper are structured around this framework.

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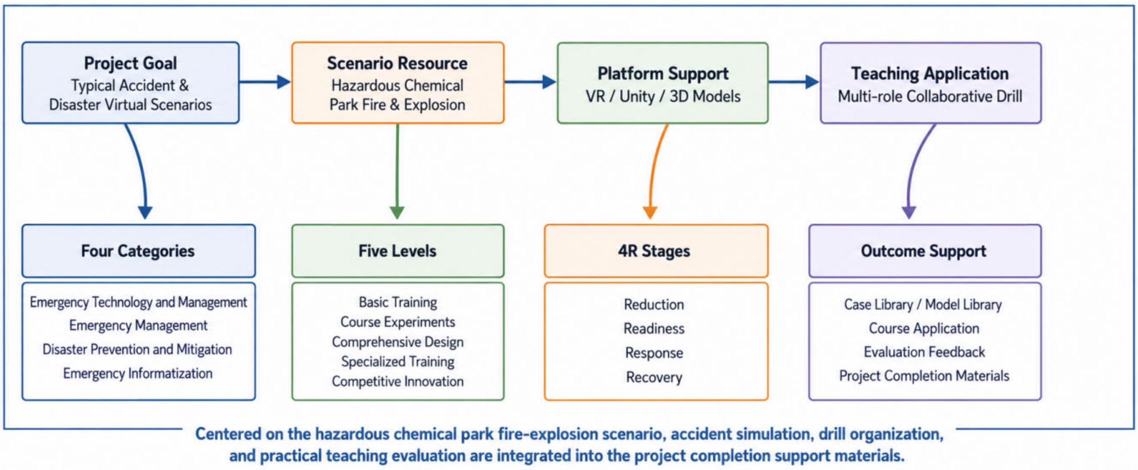

Figure 1. A Project-Oriented Research Framework for Virtual Scenarios of Post-Earthquake Buildings Using Na-tech.

3. Incident Case Reviews and Extraction of Scenario Elements

The “August 12” accident [16-18] at the Port of Tianjin was a representative major and particularly serious production safety accident involving negligence in the field of hazardous chemical storage in China. The accident occurred at the hazardous materials warehouse of Tianjin Port Ruihai International Logistics Co., Ltd. in the Binhai New Area of Tianjin. Two violent explosions occurred in succession at the site, resulting in significant casualties and property damage. The accident exhibited typical characteristics, including the illegal storage of hazardous chemicals, rapid fire spread, chain reactions of explosions, the dispersion of toxic and harmful substances, and the complexity of emergency response involving multiple departments. For the development of virtual scenarios, this accident provides a relatively comprehensive case background, spatial environment, information on hazard sources, the progression of the accident, and challenges related to rescue and response operations.

According to the original report, Ruihai Company’s hazardous materials warehouse had serious issues regarding planning approvals, fire safety inspections, safety assessments, and the management of hazardous chemical storage. The warehouse stored nitrocellulose, ammonium nitrate, sodium cyanide, and other flammable, explosive, highly toxic, and corrosive substances; furthermore, hazardous chemicals with different properties were stored together, in excess of permitted quantities, and piled outdoors. Following the accident, the nitrocellulose absorbed moisture, generated heat, and spontaneously combusted. The resulting fire ignited surrounding hazardous chemicals, which in turn caused the ammonium nitrate to decompose under heat and explode. This sequence of events demonstrates that a hazardous chemical fire is not a single combustion event, but rather a dynamic process resulting from the combined effects of the hazardous properties of the substances, storage methods, heat radiation, ventilation conditions, firefighting methods, and rescue decisions.

From the perspective of rescue and response, the incident exposed issues such as insufficient information in the early stages, a lack of clarity regarding the inventory of hazardous chemicals, insufficient basis for rescue decision-making, blocked access routes at the scene, an imperfect multi-agency coordination mechanism, a lack of specialized knowledge about hazardous chemicals among rescue personnel, and delays in environmental monitoring and evacuation control. All of these issues can be transformed into virtual drill scenarios. For example, the lack of clarity regarding the inventory of hazardous chemicals can be transformed into a “hazard source information inquiry and verification” task; obstructed rescue access routes can be transformed into a “traffic diversion and access route security” task; and environmental

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pollution risks can be transformed into a "toxic gas monitoring and dynamic adjustment of warning zones" task.

Table 1 converts information from accident case studies into elements for virtual scenario modeling. Through this conversion, the static facts in accident investigation reports can be transformed into scenario objects, parameter conditions, and mission nodes for teaching and training exercises.

Table 1. Correspondence between Information of the "8・12" Accident at Tianjin Port and Elements of Virtual Scene Modeling.

Accident Info	Core Content	Scenariocentric Expression
Hazmat storage	Multiple hazmats like nitrocellulose, ammonium nitrate, sodium cyanide	Hazard models, risk level tagging
Spatial environment	Warehouses, roads, containers, dense surrounding buildings	3D park models, road networks
Accident process	Ignition, spread, two explosions, smoke diffusion	Flames, thick smoke, explosions, diffusion animation
Rescue issues	Lack of info, blocked channels, poor coordination	Task triggers, traffic diversion, collaboration workflows
Consequences & impacts	Casualties, environmental pollution, facility damage	Casualty rescue, eco-monitoring, review & evaluation

4. Creating Virtual Fire Scenarios in Hazardous Chemicals Industrial Parks

The development of virtual fire scenarios for hazardous chemical industrial parks should follow a logical framework of "real-world cases—core data—3D scenes—dynamic processes—interactive tasks." First, based on accident investigation reports and relevant materials, information such as park roadways, warehouse zones, hazardous chemical storage areas, fire lanes, surrounding buildings, and the locations of rescue vehicles and personnel is extracted to form the foundation for scene construction. Next, use 3ds Max to create models of the park environment, storage tanks, containers, hazardous chemical packaging, firefighting facilities, vehicles, and personnel, then import, render, and configure interactions for these models in Unity 3D. Finally, set up dynamic effects such as flames, smoke, blast waves, toxic gas dispersion, and traffic congestion to ensure the scene accurately reflects the accident process rather than serving as a static display.

Figure 2. Illustration of the virtual scene construction for the hazardous chemicals park.

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Figure 3 illustrates the correspondence between the sequence of fire and explosion incidents in a hazardous chemicals industrial park and the virtual drill tasks. The sequence of incidents can be summarized as "hazardous chemicals anomaly—fire spread—explosion shockwave—toxic gas dispersion—traffic congestion—coordinated response." Each stage corresponds to a trainable task: the hazardous chemical anomaly stage corresponds to data collection and risk identification; the fire spread stage corresponds to fire situation assessment and selection of firefighting strategies; the explosion impact stage corresponds to expanding the safety perimeter and emergency evacuation of personnel; the toxic gas dispersion stage corresponds to environmental monitoring and adjustment of protection levels; the traffic congestion stage corresponds to traffic control and securing rescue routes; and the coordinated response stage corresponds to joint operations involving multiple departments, including firefighting, medical services, public security, environmental protection, and technical support.

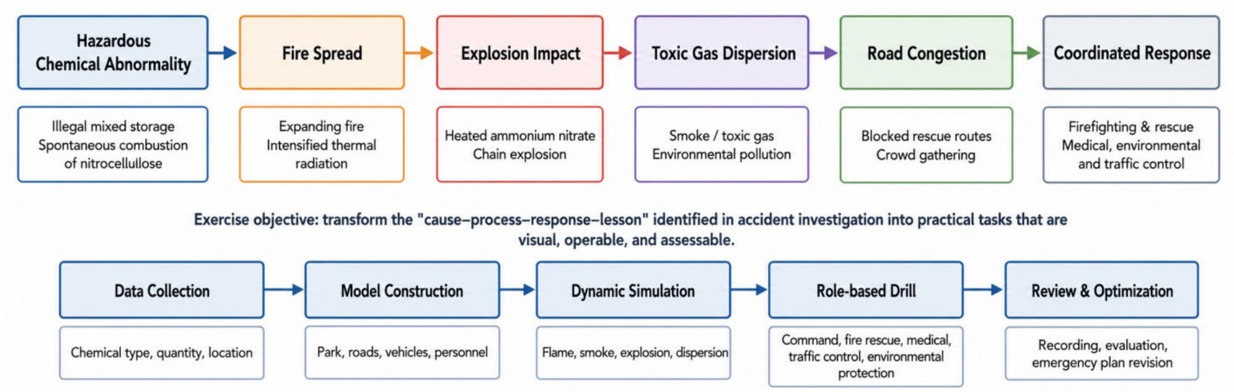

Figure 3. Chain of Fire and Explosion Incidents in Hazardous Chemicals Industrial Parks and Virtual Drill Scenarios.

In designing scene details, three key elements should be emphasized. The first category consists of spatial elements, including storage areas, loading and unloading zones, roads, perimeter fences, entrances and exits, residential areas, and rescue assembly points, which primarily support spatial awareness and route planning. The second category consists of disaster elements, including the point of origin of the fire, the site of the explosion, the direction of smoke dispersion, the range of toxic gas exposure, areas of heat radiation, and the distribution of hazardous materials, which primarily support risk identification and situational assessment. The third category consists of operational elements, including fire truck routes, the establishment of security perimeters, casualty evacuation routes, the deployment of medical stations, and the placement of environmental monitoring points, which primarily support rescue mission drills.

Virtual scenarios are not simply replicas of accident sites, but rather structured representations of the key elements of accident-based instruction. An excessive focus on visual details may lead to prohibitively high system development costs, while neglecting task logic will diminish the educational value. Therefore, this paper recommends adopting "recognizable, operable, and evaluable" as the standards for scenario development: "recognizable" means that students can clearly identify hazard sources, accident conditions, and rescue resources; "operable" means that students can complete role-based tasks and follow operational procedures; and "evaluable" means that the system can record process data and support debriefing and analysis. Table 2 summarizes the scenario resource modules proposed in this paper.

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Table 2. Virtual Scenario Resource Module Table for Hazardous Chemical Park Fires.

Resource Module	Main Content	Teaching Function
Spatial Model	Warehouses, roads, storage tanks, containers, entrances/exits	Build accident scene spatial cognition
Disaster VFX	Flames, smoke/fog, explosions, toxic gas diffusion	Demonstrate dynamic accident evolution
Role Objects	Command, firefighting, medical, traffic police, eco-protection, tech support	Support post-specific training
Contingency Workflow	Alarm receipt, reconnaissance, cordoning, firefighting, rescue, debriefing	Convert written contingency plans into task workflows
Data Records	Response time, operation logs, task completion status	Support evaluation & feedback

5. Design of Visualized Contingency Plans and Multi-Department Joint Drills

Fire rescue operations in hazardous chemicals industrial parks must adhere to the principles of unified command, tiered responsibility, scientific rescue, and coordinated response. Although traditional text-based contingency plans specify organizational structures, response procedures, mitigation measures, and support requirements, issues such as abstract concepts, unclear implementation pathways, and non-intuitive coordination relationships often arise during training and drills. The core objective of visual contingency planning is to transform the organizations, responsibilities, resources, processes, and precautions outlined in the text into actionable tasks within a virtual scenario.

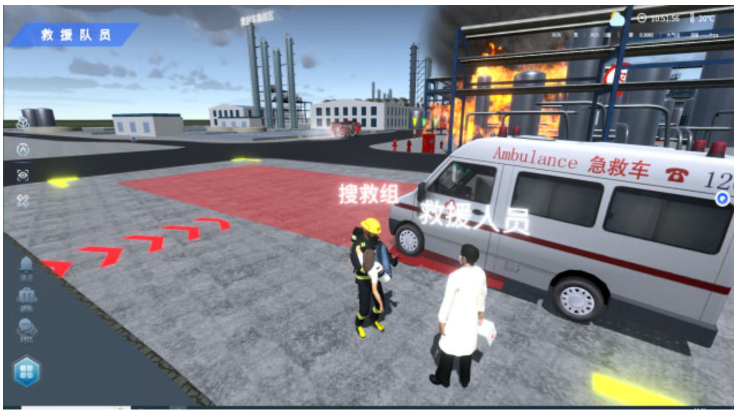

Figure 4. Design illustration of multi-department collaborative drill.

This article divides the fire rescue process for hazardous chemical industrial parks into six phases: Dispatch and Assessment, On-Site Reconnaissance, Security and Evacuation, Firefighting and Search and Rescue, Medical and Environmental Response, and Termination and Debriefing. During the Dispatch and Assessment phase, the incident commander must determine the incident level based on the emergency call information and activate the emergency response plan; during the On-Site Reconnaissance phase, fire rescue and technical support personnel must identify the types of hazardous chemicals, the locations of fire sources, and the risk of explosion; the Perimeter Security and Evacuation phase requires public security traffic management to establish a danger zone, control non-essential vehicles, and organize the evacuation of the public; the Fire Suppression and Search and Rescue phase requires

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firefighting forces to contain the fire, cool the area, isolate the fire, and conduct search and rescue operations; the Medical and Environmental Protection phase requires medical personnel to triage and treat the injured, while environmental monitoring personnel conduct monitoring for toxic gases and pollutants; and the Termination and Debriefing phase involves evaluating the response process, resource allocation, and the effectiveness of the response.

Figure 5 illustrates the process of a multi-agency joint rescue drill. This process integrates six roles—emergency command, fire and rescue, medical emergency response, public security traffic management, environmental monitoring, and technical support—into a single drill framework, with tasks progressing in stages. Its key feature is the simultaneous operation of horizontal coordination and vertical command. Vertically, commanders establish a chain of command through the issuance of tasks, receipt of feedback, and adjustment of plans; horizontally, different agencies share information and coordinate their actions around a common mission.

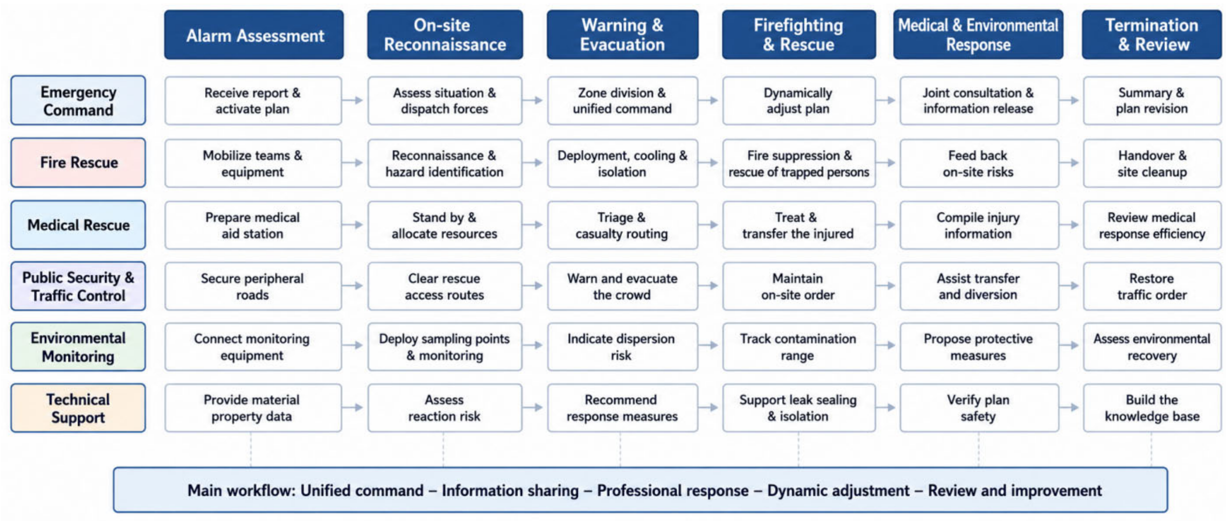

Figure 5. Procedures for Multi-Agency Joint Rescue Drills in Response to Fires at Hazardous Chemicals Industrial Parks.

Table 3 further presents a matrix of multi-role responsibilities and training tasks. This matrix can be used both for designing exercise scenarios and for instructors to assign student roles and conduct formative assessments. In the context of undergraduate emergency response education, the value of the multi-role matrix lies in helping students shift from a focus on individual task execution to an understanding of systemic coordination, making it clear that each role does not operate in isolation but is interdependent within a shared risk scenario.

Visualized contingency plans should also incorporate dynamic optimization mechanisms. Hazardous chemical fire scenes are highly unpredictable; factors such as changing wind directions, increased explosion risks, road blockages, and delays in rescue forces can all render the original plan ineffective. Therefore, virtual drills should allow instructors or the system to modify scenario parameters to trigger different response branches. For example, when wind direction changes, environmental monitoring points and cordoned-off areas should be adjusted accordingly; when roads are congested, traffic police must reroute rescue routes; and when the fire spreads to a hazardous materials storage yard, the incident commander must adjust firefighting resources and the evacuation zone. Through this design, students can understand that emergency response plans are not fixed scripts, but rather action plans that require continuous refinement based on evolving situations.

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Table 3. Matrix of Multiple Roles and Training Tasks.

Role	Main Responsibility	Training Tasks	Evaluation Focus
Emergency Command	Unified assessment & dispatch	Activate plans, allocate tasks, adjust schemes	Rationality of decision-making
Fire Rescue	Firefighting, hazard control & SAR	Recon/detection, cooling, firefighting, SAR	Standardisation of operations
Medical Rescue	Triage & evacuation	Set up aid stations, first aid, medical transfer	Timeliness of rescue care
Police & Traffic	Cordon containment & traffic diversion	Delineate cordons, maintain open channels, evacuate personnel	Effectiveness of control
Eco-monitoring	Pollution monitoring & risk alerting	Deploy monitoring sites, adjust cordon range	Accuracy of judgment
Tech Support	Material property assessment & equipment support	Provide data, support leak plugging & isolation	Feasibility of suggestions

6. Practical Teaching Applications for Undergraduate Students in Emergency Management

Incorporating a virtual fire scenario in a hazardous chemicals industrial park into undergraduate practical training for emergency response requires design at three levels: curriculum, competencies, and assessment. At the curriculum level, this scenario can support courses such as “Emergency Management Information Systems,” “Industrial Safety and Emergency Management,” “Emergency Plan Development and Drills,” “Firefighting Equipment and Fire Extinguishing Techniques,” “3S Technology and Disaster Prevention Applications,” and “Disaster Risk Assessment.” At the competency level, the scenario can develop students’ abilities in hazard identification, accident chain analysis, platform operation, contingency plan design, emergency response, collaborative communication, and post-incident review and improvement. At the assessment level, student performance can be comprehensively evaluated using metrics such as task completion rate, response time, adherence to operating procedures, effectiveness of collaboration, and post-incident review reports.

Figure 6 illustrates the correspondence between virtual scenarios involving hazardous chemicals and the “Four Categories, Five Levels, and 4R” practical framework. Horizontally, the scenarios support four academic specializations: emergency response technology and management, emergency management, disaster prevention and mitigation science and engineering, and data science and big data technology. Vertically, the scenarios can be integrated into five competency levels: basic training, course experiments, comprehensive design, professional skills training, and competition-based innovation. In terms of process, the scenarios can also be integrated with the four phases of Reduction, Readiness, Response, and Recovery. Consequently, a single accident scenario can be organized into a practical resource shared across multiple courses, disciplines, and phases.

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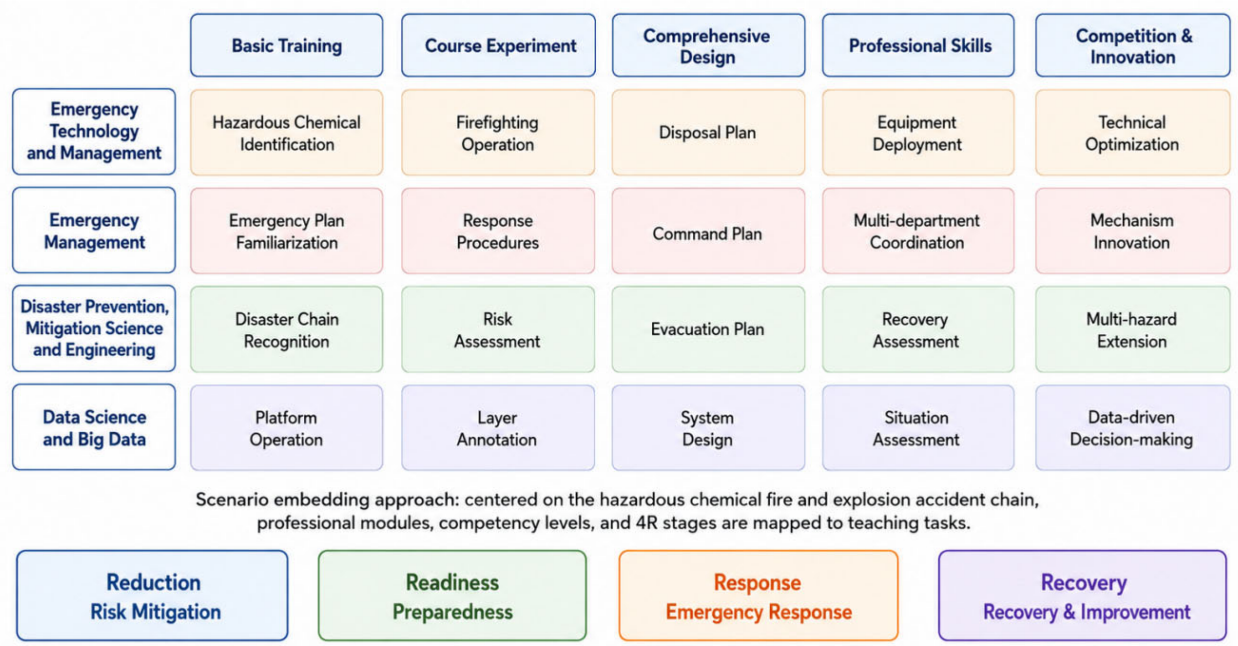

Figure 6. Correspondence between the virtual scenario of hazardous chemicals and the "four classifications, five levels, and 4R" practical system.

Table 4. Correspondence Table between Virtual Hazardous Chemical Scenarios and Practical Teaching System.

Dimension	Corresponding Content	Specific Manifestation
4-Category	4 professional directions	Emergency tech & mgmt, emergency mgmt, disaster mitigation, emergency IT
5-Level	5 types of ability training	Basic training, course experiments, comprehensive design, professional skills, competition innovation
4R Stage	Full-process emergency mgmt	Reduction, Readiness, Response, Recovery & improvement
Course Application	Specialty courses & practical links	Plan compilation, platform operation, collaborative drills, debriefing reports
Output Support	Concluding materials & resource construction	Scenario libraries, model libraries, teaching cases, evaluation forms

In teaching practice, the process can be carried out according to the following sequence: “Pre-class Learning—Scenario Introduction—Task Assignment—Role-Playing—Data Recording—Instructor Evaluation—Student Debriefing—Contingency Plan Optimization.” During the pre-class phase, students review accident case studies, basic knowledge of hazardous chemicals, and emergency response plans; during the scenario introduction phase, the instructor uses VR to demonstrate the facility layout, the distribution of hazard sources, and the progression of the accident; during the task assignment phase, students are assigned different roles; during the role-play phase, students carry out response actions in accordance with the emergency plan and the on-site situation; during the data recording phase, the platform logs key milestones and operational performance; and during the evaluation and debriefing phase, instructors and students jointly analyze procedural flaws and optimize the response plan.

Table 4 shows the correspondence between teaching applications and the project system. This table can be used directly as supporting documentation for the “matching of scenario resources with course practical components” or “verification of teaching applications” sections in the final reports for teaching reform projects. Through this design, the outcomes of graduation projects

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are no longer merely individual student works but can be transformed into a repository of project scenarios, a model library, and course practical resources.

7. Evaluation System and Effectiveness Analysis

The evaluation of virtual fire drills in hazardous chemicals industrial parks should take into account both educational outcomes and drill effectiveness. Educational outcomes focus on whether students understand the mechanisms of accidents, have mastered platform operations, are clear about their roles and responsibilities, and have developed an awareness of reviewing and improving their performance; drill effectiveness focuses on whether the response was timely, whether the handling was standardized, whether coordination was smooth, whether resource allocation was reasonable, and whether the contingency plan was practical. Traditional lab reports struggle to fully reflect these process-oriented aspects; therefore, it is necessary to establish an evaluation system based on process records.

This paper proposes conducting the evaluation based on five primary indicators. The first is scenario recognition, which primarily assesses students' ability to identify types of hazardous chemicals, the locations of hazard sources, accident sequences, and the spatial environment. Second is platform operation, which primarily evaluates students' proficiency in navigating VR scenarios, following task prompts, annotating data, and operating their assigned roles. Third is response execution, which primarily evaluates the standardization of students' performance in completing tasks such as firefighting, cordoning off the area, evacuation, medical care, monitoring, and information feedback. Fourth is collaborative communication, which primarily evaluates the transmission of instructions, information sharing, and coordination adjustments among different roles. Fifth is debriefing and improvement, which primarily evaluates students' ability to identify issues based on drill records, propose recommendations for optimizing contingency plans, and compile reports.

Table 5 lists the recommended evaluation criteria. When applying these criteria in practice, the weightings may be adjusted based on the nature of the course. If used for course-based simulations, the weightings for platform operation and situational awareness may be appropriately increased; if used for comprehensive design projects, the weightings for contingency planning and post-exercise review and improvement may be increased; and if used for professional skills training, the weightings for response execution and collaborative communication should be increased.

Table 5. Suggested Evaluation Indicators for Students' Practical Competence.

Primary Indicato	Evaluation Content	Suggested Weight
Scenario Cognition	Identification of hazards, accident chains & risk zones	20%
Platform Operation	Model invocation, task reception, status feedback	15%
Disposal & Execution	Task completion of firefighting, evacuation, rescue, monitoring	30%
Collaboration & Command	Command transmission, info sharing, consultation & adjustment	20%
Review & Improvement	Problem analysis, plan optimization, report writing	15%

In terms of expected outcomes, virtual scenario-based instruction offers three key advantages. First, it enhances the visual understanding of emergency situations. Students can observe fire spread, smoke dispersion, traffic congestion, and evacuation procedures in a three-dimensional space, making abstract concepts easier to grasp. Second, it improves the ability to apply emergency response plans. Through task-based drills, students can understand how the

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provisions of emergency response plans are translated into concrete actions. Third, it enhances awareness of coordinated response. Multi-role drills help students recognize that emergency rescue is not the work of a single department, but rather a systematic operation involving the joint participation of command, firefighting, medical services, traffic management, environmental protection, and technical support.

8. Discussion

The primary value of this paper lies not merely in the development of a VR demonstration scenario, but in the integration of typical accident case studies, virtual simulation technology, and the undergraduate practical training system for emergency response. First, case analysis provides a foundation of authenticity for scenario development, ensuring that scenario elements are derived from real-world accidents rather than being fabricated from scratch. Second, virtual simulation offers a safe avenue for teaching high-risk accident scenarios, enabling students to repeatedly practice scenarios—such as fires, explosions, toxic gas dispersion, and multi-agency coordination—that are difficult to replicate in physical drills. Furthermore, the educational reform project framework provides a curricular context for the scenario resources, enabling them to support the development of a practical training system based on the “four classifications, five levels, and 4R stages.”

Compared to traditional graduation theses, restructuring a paper in the style of a journal article requires emphasizing problem awareness, methodological framework, and practical value. This paper transforms the original topic, “Fire Simulation and Rescue Drill Design for Hazardous Chemicals Industrial Parks,” into “Research on the Development of Virtual Scenario Resources for Undergraduate Emergency Response Practical Instruction,” making it better aligned with the requirements for the completion of educational reform projects. This transformation involves reorganizing the project from the perspective of its outcomes: accident cases serve as the source of scenarios; 3D modeling constitutes resource development; rescue drills represent instructional implementation; multi-role collaboration fosters competency development; and evaluation and feedback serve as validation of the project’s application upon completion.

The study still has some limitations. First, the current scenarios are primarily based on the Tianjin Port accident and do not sufficiently cover other types of accidents in hazardous chemical industrial parks, such as liquid chlorine leaks, oil tank fires, the propagation of explosion shock waves, and hazardous chemical transportation accidents. Second, the propagation of fire, smoke, and toxic gases relies primarily on visual representations and rule-based triggers; to support more precise decision-making assistance, professional numerical simulations and real-time data coupling need to be incorporated. Third, teaching evaluation currently focuses mainly on indicator design and process documentation; in the future, student performance, questionnaire feedback, and practical training data should be collected through multiple rounds of course implementation to further validate the effectiveness of the teaching.

Future improvements can be made in three areas. First, expand the multi-hazard scenario library to incorporate scenarios such as hazardous chemical fires, post-earthquake building structural analysis, urban flooding, gas leaks, mining accidents, and traffic accidents into a unified resource system. Second, enhance the platform’s support capabilities by integrating the EGIS “Single Map,” digital asset library, experimental project library, practical training records, and knowledge base to form cloud-based resources that are shareable, accessible, and iterable. Third, introduce artificial intelligence and digital twin technologies to enhance capabilities in accident scenario simulation, rescue route planning, student behavior assessment, and automatic optimization of emergency response plans.

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