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Exploring the Pathway of Empowering Emergency Management Major Course Instruction through Science and Innovation Projects

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Abstract: Against the background of emerging engineering education reform, traditional lecture-based teaching of emergency management courses relies merely on static printed fire cases, which cannot create dynamic fire scenarios for students to practice emergency judgment. Our teaching group carried out a one-year classroom teaching pilot based on the college student innovation project of intelligent building fire evacuation simulation system. We decomposed the complete technical system including multi-source sensing, edge AI identification and improved A* dual-objective algorithm into graded classroom learning tasks matching different learning levels. Teaching data collected from 83 undergraduates shows that students' scores on dynamic scenario judgment rise significantly after the reform, and their learning initiative is greatly improved. This paper sorts out the operable classroom implementation methods of transforming innovation project achievements into teaching materials, which can provide practical references for fire-related courses of emergency management majors in other universities.

Keywords: College Innovation Project; Emergency Management Major; Digital Twin; Classroom Teaching Reform; Virtual Fire Simulation.

1. Introduction

1.1. The Core Contradiction in Emergency Management Major Course Instruction

As a cross-discipline major combining safety, management and information technologies, emergency management puts high demands on students' practical disaster response skills[1]. Our training targets require learners to master systematic theories and make fast, rational judgments under complicated, high-stress emergency scenes.

Yet we have run into a persistent teaching dilemma when delivering core modules including Building Fire Protection and Evacuation, Emergency Command and Decision-Making and Safety Monitoring and Early Warning. Emergency handling abilities can only be polished via repeated practice in lifelike scenarios. In reality, safety risks, limited venues and high operating costs stop us from staging real fire or collapse drills on campus. Most of our classes can only rely on textbook theories and static case descriptions. Students barely get chances to practice on-scene judgment, and we lack effective teaching tools to train their emergency decision-making capacity[2]..

1.2. Integrating Science and Innovation Projects into Course Instruction: A Feasible Breakthrough

Over recent years, many universities have started to link research work with daily classroom teaching to update their undergraduate courses[3]. Our team also finds student innovation projects can serve great teaching value. These projects are built around real campus safety issues. Students follow a clear learning path: spotting practical hazards, designing corresponding solving schemes, testing their ideas, and adjusting plans based on test results. Such full-cycle practice offers vivid learning materials for our fire safety lessons.

Integrating science and innovation projects into professional course instruction can address the aforementioned instructional dilemma from at least three levels. First, the technological outputs of these projects—simulation systems, algorithmic models, data platforms, and more—can be directly transformed into instructional resources, providing high-fidelity training vehicles for practical teaching. Second, the research process inherent to these projects—problem definition, solution design, experimental validation, and result analysis—constitutes a complete pathway for competency development that can be transplanted into the instructional process. Third, the cutting-edge and exploratory nature of science and innovation projects stimulates students' intellectual curiosity and innovative awareness, effectively enhancing intrinsic learning motivation in the classroom[4].

Based on the above analysis, this paper takes the core courses of the emergency management major as the application context and the "Intelligent Fire Evacuation Virtual Simulation Experiment Project" as a typical case to systematically explore the implementation pathway through which science and innovation projects empower course instruction.

2. Project Overview and Pedagogical Transformation

2.1. Core Technological Outcomes of the Science and Innovation Project

To address the problem that static evacuation signs cannot cope with heavy student crowds and shifting smoke hazards during classroom breaks, our research team developed a complete fire warning and evacuation virtual simulation system combining multi-point sensing, edge computing and digital twin technology as described in literature[5]. The platform consists of four practical functional parts: the multi-dimensional sensing unit gathers gas, temperature and visual signals together and cross-verifies data to filter classroom interference such as chalk dust; the Jetson Nano edge device runs simplified YOLOv5-FIS algorithms to spot flames and smoke within 200 ms offline, supported by LoRa and WiFi dual communication backup; the Unity 3D digital twin model built from BIM drawings integrates FDS fire and Pathfinder crowd simulation engines to visualize real-time hazard changes[6]; we also improved the standard A* algorithm by adding angle and congestion weighting factors to balance evacuation speed and safety risk, updating escape routes every 5 seconds and shortening overall evacuation time by 15.5% in tests [7].

All four self-built modules fit perfectly into our fire safety course teaching. In regular classes, we can separate each component for targeted learning activities: students study monitoring hardware with the sensing unit, practice lightweight AI recognition via edge equipment, conduct full-scene emergency drills in the 3D twin environment, and design comparative evacuation experiments using the optimized path algorithm, making the whole research project a usable set of classroom teaching materials.

2.2. The Transformation Pathway from Project Outcomes to Instructional Resources

We cannot just import the whole simulation platform into class and ask students to operate it directly. Instead, we reorganized the platform's functions according to undergraduate learning rules to match different teaching stages. We adopted three practical ways to adapt this research tool for daily lessons.

First, we split the integrated system into different learning layers for students of varying abilities. New learners only need to use the basic interface to view fire evacuation results; students with medium proficiency can adjust scene parameters to compare different fire responses; advanced learners can access core algorithm codes and modify relevant parameters to carry out secondary design. This multi-layer setup ensures all students can find suitable learning tasks on this single platform. Second, we designed a series of connected learning activities based on real campus fire accidents. Centered on the real issue of classroom fire evacuation, we split the whole learning process into four linked tasks, matching each task with one functional module of our platform. As students finish each task step by step, they naturally master fire detection, smoke prediction, route planning and scheme optimization knowledge. Third, we integrated research thinking into daily class activities, as referenced in document [8]. Original project development follows a research workflow, while classroom teaching focuses on guiding students to build basic knowledge first. We did not abandon the research logic but simplified it and embedded it into hands-on sessions. After finishing simulation exercises, we organize discussions to let students sort out complete research ideas, cultivating their way of thinking as safety researchers.

3. Design of the "Three-Tier Progressive" Course Instruction Pathway

3.1. Tier One: Foundational Cognition--Principle Understanding and System Familiarization

Instructional Objectives: To enable students to establish a fundamental understanding of the intelligent fire early warning and evacuation system, comprehend the working principles and functional roles of each technological module, and master basic system operations.

Instructional Content: This tier comprises three cognitive units. The first unit, "Multi-source Perception and Intelligent Recognition Principles," allows students to view three-dimensional models of various sensors, working principle animations, and real-time data acquisition demonstrations through the platform, gaining an understanding of the basic principles of smoke detectors, temperature sensors, gas sensors, cameras, and other equipment. By adjusting image input parameters, students observe variations in YOLOv5-FIS model recognition confidence, gaining preliminary insight into the working mechanisms of deep learning models. The second unit, "Digital Twin Scene Exploration and System Operation," enables students to freely navigate the three-dimensional teaching building scene, familiarizing themselves with the building structure, safety exit locations, and evacuation route layouts while mastering basic operational procedures. The third unit, "Observation and Analysis of Typical Evacuation Cases," involves the system automatically running typical evacuation cases under different fire source locations and crowd densities, with students observing the complete evacuation process as passive viewers to establish an intuitive understanding that "dynamic evacuation outperforms static signage."

The basic learning segment adopts a blended teaching mode combining live display, independent computer practice and interactive Q&A. Teachers demonstrate each functional unit's operation flow in advance. Students finish standard simulation exercises on classroom devices. System back-end data can track the whole class's learning progress and task completion quality. Teachers summarize common errors in unified explanations and give targeted guidance to students with weak performance.

3.2. Tier Two: Comprehensive Training—Scenario Simulation and Decision-Making Practice

This stage focuses on cultivating students' capacity to handle full fire response workflows under simulated environments. After learning basic system operations, learners are required to finish fire identification, hazard evaluation and evacuation scheme release independently, so as to grasp standard emergency response logic and judge shifting disaster situations rationally.

Three categories of simulation tasks are designed for classroom practice. First, fixed single-fire scene drills set fixed ignition spots and initial crowd layouts. Students check multi-sensor data, observe smoke spread via digital twin models and generate evacuation routes with path algorithms. The platform records every operation step and outputs quantitative evaluation results covering decision logic and operation efficiency for individual learning evaluation.

Second, comparative simulation with variable conditions allows learners to adjust fire floors, occurrence time and crowd types such as people with limited mobility. They contrast evacuation schemes under different settings and write analytical records to strengthen situational judgment. Third, group collaborative drills divide learners into teams of four to five, with each member taking charge of fire monitoring, overall command or on-site evacuation guidance. Participants rotate roles to experience all emergency posts and improve coordination during disasters.

Classroom teaching relies on assigned tasks, group cooperation and real-time system feedback. Teachers distribute standardized task lists with clear time limits for each group to submit simulation outputs. The embedded evaluation function marks operations instantly and sorts out typical errors. Teachers pick representative evacuation schemes for whole-class sharing and discussion, helping learners deepen understanding through practice and error analysis.

3.3. Tier Three: Innovative Design—Inquiry-Based Experimentation and Plan Optimization

This part targets students with solid foundational knowledge, and it can also be used as the core content of course assignments or undergraduate thesis research. Its core goal is to train learners to discover practical problems, design comparative experiments and carry out critical analysis after they master basic system operation rules.

Two open research activities are arranged for in-depth learning. The first activity focuses on the comparison of evacuation route algorithms. The system integrates classic A*, upgraded dual-target A* and ant colony algorithms for learners to test under identical fire scenes. By tuning weight parameters related to travel angle and crowd congestion, learners may observe the gap of evacuation efficiency among different algorithms. Heat distribution graphs, route overlay charts and time accumulation curves are supplied for data visualization, and learners need to finish full experimental documents covering experimental setup, raw data recording and result discussion to train standardized research thinking. The second activity allows self-defined scene construction. Learners can adjust corridor width, exit positions and building structures via the built-in editing tool, and add special groups with movement difficulties or sudden road barriers to build unique fire scenarios. Schemes with reasonable design and reliable test results can be collected into the platform's teaching case bank to motivate students' independent exploration.

Learners carry out research either alone or in small teams under teachers' regular tutoring. They pick research themes, finish experimental testing and compile complete analysis reports, and finally share their design results through class presentations. The simulation platform offers built-in data recording and visual output functions to reduce technical barriers for students who conduct exploratory learning independently.

4. Instructional Implementation and Effect Analysis

4.1. Implementation Arrangements

The teaching practice of this simulation platform was carried out on the core course Building Fire Protection and Evacuation for emergency management undergraduates at XX University throughout the 2025–2026 academic semester, with a total cohort of 83 participants. The whole course takes up 48 class hours, split evenly between theoretical lectures and computer-based simulation drills. The training sessions built around the student innovation project are allocated with differentiated time arrangements: six hours are reserved for introductory learning that covers system framework recognition and basic scene operation; fourteen hours are set aside for integrated fire scenario drills with three sequential practice modules; another four hours are arranged for small-group exploratory work on evacuation algorithms and custom fire scheme design. For evaluation purposes, the course adopts a two-part grading framework. Daily learning performance accounts for sixty percent of the total grade, which is broken down into four parts: operation records, written training reports, group teamwork performance and pre-class online learning. The remaining forty percent comes from the final comprehensive simulation task evaluation.

4.2. Data Collection Methods

Multiple types of evidence were collected to judge how the new teaching mode worked, covering numerical records and subjective feedback from students.

Numerical evidence was gathered from three channels. First, the same set of fire emergency test papers was given to learners before and after the whole semester's study. The test paper contained ten scenario judgment questions about fire response and route arrangement, plus five fill-in items checking basic theoretical knowledge, with a three-month gap between two rounds of tests. Second, the simulation system automatically saved each learner's operating records, such as how long they spent practicing and the accuracy of their evacuation choices. Third, all participants filled out anonymous five-scale questionnaires after finishing the course to share their real feelings about the training design.

For subjective supporting materials, researchers sorted through students' experiment summary documents and held three separate group talks. Each discussion group had six to eight learners, and conversations centered on their real learning experience and feasible suggestions to optimize future teaching arrangements.

4.3. Effect Analysis and Discussion

(1) Competency Enhancement Effects

Statistical comparison of pre-semester and post-semester exam results revealed obvious score growth across all participants. Before the new training mode, the average exam score stood at 61.4 with a standard deviation of 10.5, while the average rose to 83.7 (SD=8.2) after the course, with the paired t-test output t=15.23 and p less than 0.001, which proves the score difference carries statistical significance, with an average score rise of 22.3 points. Questions requiring analysis of real fire scenarios saw an average improvement of 28.6 points, much higher than the 12.1-point gain on memorization-focused items. This contrast shows simulation drills work far better at shaping students' ability to analyze dynamic fire hazards and pick reasonable evacuation solutions. Out of 83 total students, 71 (85.5%) earned higher marks on scenario analysis tasks, and nearly half of all learners (39 people, 47.0%) saw their scenario scores jump by more than 30 points.

(2) Learning Behavior Characteristics Analysis

Data exported from the platform's background recorded each student's operating records during integrated practice sessions. On average, every student spent 4.2 hours on simulation practice and repeated each set of training tasks about 2.7 times. This pattern demonstrates most learners refined their evacuation plans continuously by testing different settings, checking the system's feedback, and adjusting their choices accordingly. The accuracy of students' emergency judgments also climbed noticeably: the average hit rate only reached 58.3% on their first attempt, but grew to 81.7% by the end of all scheduled training. Such data verifies that repeated simulated practice effectively improves students' emergency handling skills. Besides mandatory class tasks, 22 students (26.5%) chose to log into the platform voluntarily for extra practice after class, and six of them finished comparative testing for all pre-set fire scenes. This active participation reflects that the simulation platform successfully raises students' willingness to take initiative in learning fire emergency knowledge.

(3) Student Satisfaction and Learning Experience

Eighty valid questionnaires were collected (effective response rate 96.4%). Satisfaction scores across dimensions are presented in Table 1.

Table 1. Satisfaction scores across dimensions

Evaluation Dimension	Mean Score	Satisfied/Very Satisfied Percentage
Relevance of training content to course theory	4.41	87.5%
Realism and immersion of virtual simulation scenes	4.35	85.0%
Value of training tasks for decision-making competency development	4.52	91.3%
System usability and interaction smoothness	4.18	78.8%
Novelty and appeal of integrating science and innovation projects into the classroom	4.48	88.8%
Perceived help in understanding research methodologies	4.33	83.8%

In focus group interviews, students commonly reported positive experiences including: "The virtual scene is much more vivid than case studies—you can really feel the pressure of decision-making"; "Adjusting parameters and seeing real-time feedback leaves a deeper impression than the instructor directly explaining the principles"; "The multi-role exercise made me realize that emergency response is not an individual effort—every role is critical." Some students suggested adding more types of building scenarios (e.g., dormitories, libraries) and improving network synchronization during multi-role collaboration.

(4) Reflections on the Empowerment Pathway of Science and Innovation Projects

Synthesizing the above instructional practice, four effective lessons for empowering course instruction through science and innovation projects can be distilled:

First, transformation must be layered. Decomposing complex project systems into instructional modules with varying cognitive loads is the foundational prerequisite for ensuring empowerment effectiveness. The same technical system should be presented differently to first-year students versus senior students—a one-size-fits-all approach is inappropriate.

Second, problems must be authentic. The greatest attraction of science and innovation projects to students lies in their responsiveness to real-world problems. Instruction should consistently use real fire cases and actual data as contextual anchors, avoiding the dissipation of the project's authenticity and impact through excessive "pedagogical packaging."

Third, feedback must be immediate. The greatest instructional advantage of simulation environments lies in their ability to provide immediate, visual, and comparable operational feedback. Instruction should fully leverage this advantage, ensuring that students receive clear directions for improvement after each operation rather than merely a vague score.

Fourth, assessment must be multidimensional. The open-ended nature of science and innovation projects determines that student learning outcomes take diverse forms (operational logs, analytical reports, optimization plans, teamwork, etc.). Single-dimensional assessment cannot fully reflect student learning effectiveness, necessitating the construction of multidimensional, process-oriented assessment frameworks.

5. Experience Summary and Dissemination Recommendations

5.1. Core Experiences

This research selects the virtual simulation platform for campus fire evacuation as a practical sample to analyze how undergraduate research projects can be adapted to fit emergency management teaching. A set of operable rules for curriculum reform are summed up after theoretical sorting and one semester of classroom trials.

The first core rule concerns matching research tools with students' cognitive levels. Technical systems developed for research follow logic different from classroom teaching frameworks. Directly introducing complete research tools into courses cannot bring ideal learning effects. The whole simulation platform needs to be split into multiple progressive learning modules covering basic recognition, practical operation and independent exploration. Such hierarchical arrangement guarantees learners at different stages can grasp knowledge matching their current ability.

Realistic campus safety issues serve as another vital driving factor for active learning. Standard textbook teaching mostly relies on exams to push students to study, while research-based training links every operation to real fire safety risks. Once learners realize their evacuation choices relate to the safety of actual teachers and students, they will treat learning as a social responsibility instead of a compulsory assignment, which cannot be replicated by ordinary teaching arrangements.

Third, simulation environments render "decision-making competence" teachable. Emergency decision-making competence has long been regarded as a form of practical wisdom that can only be "understood but not expressed," difficult to effectively convey through classroom lectures. The value of virtual simulation environments lies in externalizing, operationalizing, and evaluating decision-making processes—every path choice, diversion decision, and timing judgment is recorded, fed back, and quantified—rendering "decision-making competence" a repeatedly trainable and observably assessable instructional objective.

Fourth, science and innovation projects and course instruction exhibit a bidirectional empowerment relationship. This case not only validates the empowering value of science and innovation projects for course instruction but also reveals a set of often-overlooked reverse effects: students' repeated operation of system functions exposes algorithm deficiencies in edge conditions, providing user-perspective feedback for subsequent technical iteration. In this case, the issue of "oversimplified parameter settings for populations with mobility impairments" raised by students during custom scenario experiments directly drove the project team to pursue algorithmic improvements in that direction. Course instruction thus becomes a "user testing ground" and "demand source" for science and innovation projects, suggesting the potential for a sustainable mutually reinforcing relationship between the two.

5.2. Dissemination Recommendations

The teaching mode built around this fire evacuation simulation platform can be transplanted to other universities and relevant disciplines, and targeted suggestions are sorted out for different application scenarios.

For majors closely related to safety work, such as Safety Engineering, Fire Protection Engineering and Public Administration, the progressive multi-stage teaching design summarized in this paper can be adjusted to match local curriculum arrangements. Teachers are advised to launch this teaching practice on one core course with a single simulation task first. After collecting enough teaching experience, schools can expand this training mode to a series of interrelated courses step by step.

For engineering majors focusing on information technology including Internet of Things, artificial intelligence and data analysis, the core reference value of this research is not the fire evacuation technology itself, but a complete set of methods to convert research achievements into classroom teaching materials. Teachers can split their own research projects into hierarchical modules, design practice tasks around real professional problems and integrate research thinking into class activities, so as to develop unique simulation training content matching their own disciplines.

In terms of resource sharing between different schools, existing public platforms for virtual simulation teaching can be used to exchange mature training cases. All core functional modules of this platform adopt unified standard interfaces. Schools only need to replace BIM building models and scene parameters to create customized fire simulation scenes without rewriting underlying algorithm programs, which greatly reduces the cost of secondary development. Universities carrying out relevant teaching can also submit self-built fire scenarios and excellent student design works to the public resource library. Continuous resource supplement can form a long-term sharing cycle that brings teaching benefits to all participating schools.

6. Conclusion

Carrying out course teaching with the support of student research projects is a feasible way to optimize talent training schemes under new engineering construction requirements. This paper takes emergency management undergraduate teaching as the research background and a self-developed fire evacuation simulation platform as the research object, detailing concrete operation modes and internal logic of applying research achievements to daily lessons.

Semester-long teaching trials prove that properly restructured research platforms can supply highly realistic practice carriers for practical-oriented majors like emergency management. By reorganizing research workflows into classroom activities, schools can guide students to move from basic knowledge learning to ability training and independent innovative exploration. Moreover, teaching content built on real campus safety risks can strengthen students' internal learning drive and their sense of professional recognition.

The teaching scheme summarized in this paper can be adopted and adjusted by emergency management and other safety-related majors, and it also provides a practical reference for colleges aiming to combine research outputs with classroom teaching. Follow-up work will keep tracking long-term teaching changes brought by the simulation platform, conduct deeper analysis on how research projects improve classroom quality, and expand the application scope of this teaching tool to cover more courses and student groups.

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