Integrating Ethics into Simulation-Driven Engineering Education: A Traffic Signal Control Experiment

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Abstract. Integrating ethics into engineering education is essential for cultivating socially responsible professionals. This study presents a traffic simulation-based experimental pedagogy that embeds ethical reasoning into a traffic signal control course. A "semi-flipped + semi-autonomous" teaching model is proposed, guiding students through field investigation, traffic simulation, scenario design, and multi-dimensional evaluation against technical (delay, queue length) and ethical (equity, safety, sustainability) criteria. Implementation results demonstrate enhanced technical proficiency, ethical awareness, and collaborative skills. The framework offers a replicable approach for integrating value-based education into simulation-driven engineering curricula.

Keywords: Traffic Simulation, Ethics Integration, Experimental Teaching, Traffic Signal Control, Engineering Education

1 Introduction

Traffic simulation serves as a powerful platform for integrating ethical reasoning into engineering education[1]. While traditional curricula emphasize technical skills such as data analysis and infrastructure planning, they often underemphasize the societal implications of engineering decisions [2]. However, cultivating socially responsible engineers is increasingly critical for sustainable urban development [3].

Experimental teaching bridges theory and practice, offering an effective context for embedding ethics into professional training [4]. Rather than treating ethics as isolated content, integrating it into hands-on activities fosters moral awareness and critical thinking. Yet achieving this integration requires interdisciplinary design, relevant case materials, and learner-centered instructional strategies [5].

This study addresses these challenges through the "Traffic Management and Control" course at Tongji University, focusing on a signal control simulation experiment. We propose a "semi-flipped + semi-autonomous" instructional model that embeds ethical considerations—pedestrian safety, traffic equity, and sustainability—into each experimental phase. The framework aims to provide a replicable approach for inte-

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grating ethics into simulation-based engineering education, aligning technical training with societal needs and the United Nations Sustainable Development Goals.

2 Challenges in Integrating Ethics into Experimental Teaching

Integrating ethics and social responsibility into experimental teaching presents critical challenges in engineering education. Despite growing recognition of its importance, several obstacles hinder systematic implementation.

2.1 Alignment Between Technical Content and Ethical Values

A primary challenge lies in achieving natural alignment between technical content and value-based learning objectives. Traditional experimental curricula prioritize technical competencies such as software operation and data analysis, while ethical reasoning remains peripheral [6]. Effective integration requires that values like sustainability and equity be seamlessly embedded into experimental activities without disrupting instructional flow[7]. In transportation engineering, for instance, students should evaluate signal control strategies not only through vehicular throughput but also via pedestrian safety, accessibility, and environmental impact—fostering a dual perspective that frames ethical awareness as core professional competency.

2.2 Systematic Implementation Framework

A second challenge involves developing a universally adaptable framework for consistent ethics integration across experimental courses. Current efforts remain fragmented, lacking coherent guidelines and institutional support. A robust framework requires: (a) curriculum redesign with clearly defined value-based learning outcomes; (b) resource development incorporating ethical prompts, dilemmas, and real-world cases; and (c) assessment tools that evaluate both technical proficiency and ethical reasoning [8]. Addressing these dimensions collectively fosters environments where ethical awareness is systematically nurtured alongside technical expertise, moving beyond narrow skill acquisition toward cultivating globally minded engineers.

3 Case Experiment Design

3.1 Experimental Context

The Traffic Management and Control course at Tongji University, established in 1986 as a core undergraduate course for transportation engineering students, integrates character formation with technical mastery and theory with practice. Recognized as a National First-Class Undergraduate Course (2020), its experimental component—introduced in 1995—has been continuously refined. The Signal Control and Simulation Analysis for Planar Intersections experiment, based on the traffic simulation platform VISSIM [9], requires students to apply theoretical knowledge to redesign traffic channelization for a real-world site using field-collected data. Students evaluate three signal control strategies—current situation, fixed-time, and actuated—through technical (delay, queue length) and ethical (pedestrian safety, equity, sustainability) criteria, fostering ethical decision-making, sustainability awareness, and collaborative learning.

The experiment integrates ethics through: (a) Ethical Decision-Making: assessing pedestrian safety and accessibility alongside vehicular throughput; (b) Sustainability Awareness: using simulation outputs on fuel consumption and emissions [10]; and (c) Collaborative Learning: negotiating competing priorities such as vehicle delay versus pedestrian waiting time.

3.2 Experimental Objectives

The experiment aims to: (a) contextualize technical knowledge of real-world traffic management; (b) strengthen competency in designing and evaluating fixed-time and actuated signal control systems; (c) develop hands-on proficiency in VISSIM modeling and performance analysis; and (d) foster ethical and social awareness through critical evaluation of equity and environmental impacts of signal strategies.

3.3 Experimental Procedure

The experiment combines field surveys with simulation-based learning in five phases (Figure 1), each designed to embed ethical reasoning through experiential learning.

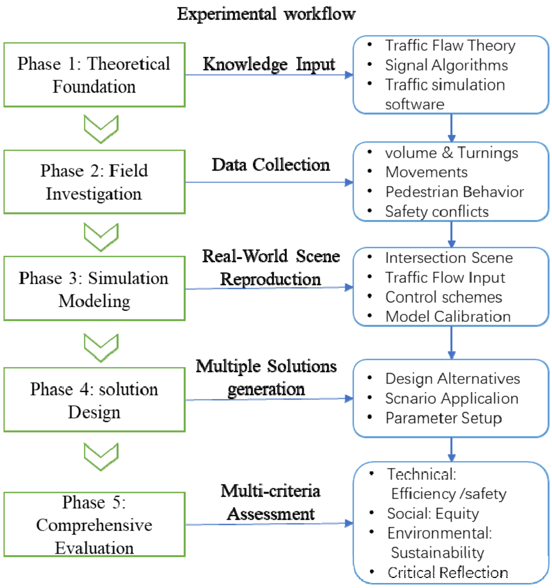

Fig. 1. Experimental produce

Phase 1: Theoretical Foundation – Lectures on traffic flow theory, signal timing algorithms, and VISSIM protocols. Ethical Mechanism: Links technical concepts (e.g., signal timing) to their ethical implications (e.g., pedestrian equity), establishing ethics as integral to engineering analysis.

Phase 2: Field Investigation – Students collect vehicular (volume, turning movements) and pedestrian (crossing patterns, wait times) data to identify real-world safety and efficiency issues. Ethics: Direct observation of vulnerable road users serves as an empathy-building catalyst, transforming abstract social responsibility into tangible experience.

Phase 3: Simulation Modeling – Students build the intersection scene in VISSIM, input traffic data and current signal schemes, and calibrate parameters to ensure simulation accuracy. Ethics: Translating field conditions into simulation parameters forces explicit choices about what to measure—embedding ethical considerations (e.g., pedestrian delay) directly into technical modeling.

Phase 4: Solution Design – Students develop alternative signal control schemes (fixed-time, actuated, transit-priority) and integrate infrastructure adaptations (e.g., pedestrian islands). Ethics: Generating multiple alternatives operationalizes value pluralism, teaching students that engineering judgment involves value-based trade-offs, not just technical calculation.

Phase 5: Comprehensive Evaluation – Students assess solutions against efficiency (delay, queue length), equity (pedestrian wait time, conflict frequency), and sustainability (fuel consumption, emissions) metrics, cultivating systems thinking and evidence-based decision-making. Ethics: Generating multiple alternatives operationalizes value pluralism, teaching students that engineering judgment involves value-based trade-offs, not just technical calculation.

4 Implementation Framework

4.1 Pedagogical Framework

This simulation-driven experimental framework aims to cultivate transportation engineers who are both technically proficient and ethically accountable. Two interrelated goals guide the design: (a) enhance problem-solving competence by enabling students to apply VISSIM simulation to real-world traffic management challenges [11]; and (b) cultivate holistic professionalism by nurturing ethical awareness, social responsibility, collaborative capacity, and systems thinking through iterative design and evaluation cycles.

The pedagogical design is grounded in experiential learning theory, which posits that deep learning occurs through cycles of concrete experience, reflective observation, abstract conceptualization, and active experimentation. Each experimental phase corresponds to one stage of this cycle: field investigation provides concrete experience; simulation modelling and evaluation enable reflection on ethical trade-offs; and solution design constitutes active experimentation with value-based decision-making. This cyclical structure ensures that ethics is repeatedly encountered as an integral dimension of engineering problem-solving, not as an isolated module.

4.2 Implementation Strategies

4.2.1 Curriculum and Resource Redesign. To embed ethics within simulation-driven experimental teaching, the course syllabus and experimental manuals were systematically redesigned. Four instructional modules structure the learning process: Collaborative Governance, Regulatory Compliance, Sustainable Development, and Responsibility Cultivation. The experimental component aligns with the final module, emphasizing hands-on ethical reasoning through simulation-based problem solving.

Key revisions to the Experimental Manual include: (a) simulation-based case studies (e.g., traffic safety incidents modeled in VISSIM) to contextualize social responsibility; (b) structured data interpretation tasks requiring systematic evaluation of simulation outputs; and (c) reflective prompts integrated into simulation tasks—such as "How can signal timing be adjusted in VISSIM to better protect vulnerable road users?"—to stimulate moral reasoning and critical thinking [12].

4.2.2 Assessment System Innovation. A dual-focused assessment framework was developed to evaluate both technical proficiency and ethical reasoning within the simulation experiment. Table 1 outlines the core criteria, integrating simulation performance metrics with reflective and equity-oriented evaluation dimensions.

Table 1. Assessment framework for simulation-driven ethics integration

Dimension	Component	Focus	Key Criteria	Simulation Context
Technical Proficiency	Experimental Report	Modeling Accuracy	VISSIM model calibration, data integrity, parameter validation	Intersection scene construction, traffic input configuration
	Critical Thinking Task	Problem-Solving	Signal timing logic, conflict mitigation strategies, feasibility	Comparative analysis of fixed-time vs. actuated control schemes
Ethical & Social Responsibility	Experimental Report	Value-Based Evaluation	Pedestrian equity (wait time), safety (conflict), sustainability (emissions)	Multi-criteria assessment of simulation outputs
	Critical Thinking Task	Human-Centered Design	Vulnerable road user protection, accessibility considerations	Scenario design with pedestrian priority and transit accommodation
Professional Development	Reflective Assignment	Self-Reflection	Team collaboration, ethical awareness, professional identity	Written reflection linking simulation decisions to societal impacts

4.2.3 Case-Based Learning Integration. Case studies serve as the bridge between simulation-based technical content and value-oriented education [11].

The experiment integrates case-based methods through the following approaches:

- Contextualized Case Selection: (a)Safety-Critical Incidents: Pre-lab discussions on historical accidents at a specific intersection, modeled in VISSIM to highlight the ethical implications of engineering decisions. (b)Comparative Simulation Exemplars: Visual materials contrasting ineffective designs (e.g., congestion caused by poor signal timing) with optimized VISSIM schemes that improve safety, equity, and environmental performance.
- Multimodal Engagement Strategies: (a)Visual Analytics: Use of simulation-generated infographics to compare performance across efficiency (delay, queue length), safety (conflict frequency), and environmental (emissions) indicators. (b) Role-Playing Scenarios: Students assume roles such as policymakers or community stakeholders, balancing technical constraints derived from simulation outputs with broader societal interests.

The detailed integration of ethical cases within the simulation-driven experimental workflow is illustrated in Figure 2.

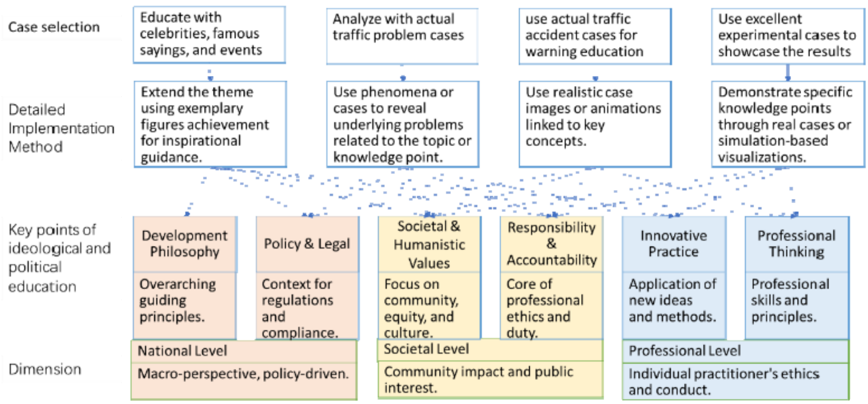

Fig. 2. Framework for ethics integration in the experiment

4.3 Implementation and Outcomes

Prior to the simulation experiment, students study revised manuals and VISSIM tutorials, conduct preliminary intersection surveys, and formulate questions—fostering proactive inquiry. The "semi-flipped, semi-autonomous" model [13-14] integrates guided in-class instruction (1.5 hours) with out-of-class autonomous exploration (2 hours).

In-class sessions embed ethical reasoning throughout the simulation workflow: a 5-minute briefing uses accident cases modeled in VISSIM to frame safety as an ethical imperative; a 10-minute theory review covers signal control principles and simulation performance metrics; a 25-minute stepwise VISSIM demonstration ensures hands-on proficiency in intersection modeling and scenario design; and a 5-minute analytical framework introduces dual technical–ethical evaluation criteria, prompting students to consider efficiency–equity trade-offs when interpreting simulation outputs.

Out-of-class, student teams independently conduct field surveys, design alternative signal control schemes, and run comparative simulations in VISSIM. Instructors provide timely feedback, reinforcing both technical rigor and ethical reflection throughout the simulation-driven design process.

Feedback from multiple cohorts confirms the effectiveness of this simulation-integrated pedagogical model. All participants (100%) reported substantial improvement in VISSIM proficiency; post-experiment surveys showed a 93% increase in awareness of sustainability and equity considerations when evaluating simulation outcomes; and 87% of teams demonstrated high-level collaboration during simulation tasks. Alumni tracking indicates 30% faster workplace adaptability, attributed to systematic problem-solving and stakeholder-centered design thinking developed through the simulation experiment.

The course has been recognized as a Tongji University Exemplary Experimental Project and a first-batch Ministry of Education Curriculum Ideological and Political Demonstration Course. Student evaluations consistently average 9.8–10.0/10, providing robust quantitative evidence of sustained teaching quality.

5 Conclusion

This study presents a simulation-driven framework for integrating ethics and social responsibility into engineering laboratory courses. Through curriculum redesign, process-embedded ethical integration, and a "semi-flipped, semi-autonomous" pedagogy, the model achieves synergistic development of technical competence, ethical awareness, and collaborative skills within a VISSIM-based traffic signal control experiment. Students learn to evaluate engineering solutions from both technical and societal perspectives—positioning equity, sustainability, and accountability as operative design criteria alongside traditional performance metrics such as delay and queue length.

The framework's effectiveness is evidenced by consistent teaching evaluations and measurable simulation-based learning outcomes. A key limitation is its reliance on context-specific cases and local traffic scenarios; successful adaptation to other settings requires careful selection of relevant materials and iterative instructional refinement. Nevertheless, this work offers conceptual and methodological guidance for integrating value-based education into simulation-driven engineering curricula, demonstrating how ethical reasoning can be embedded within technical problem-solving without disrupting core disciplinary learning.

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