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Integrating Digital Intelligence into Transportation Economics Education: A Teaching Reform Based on ADDIE-PBL Framework for Sustainable Development

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Abstract

The global push toward Sustainable Development Goals (SDGs) demands that transportation education equip students with integrated skills in data analysis and sustainability. Traditional curricula, however, often lack digital intelligence tools and multidimensional (economic-social-environmental) analysis training. This study reformed the Transportation Economics and Analysis course by integrating Virtual Reality (VR), Python, GIS, Tableau, and a blended learning platform within a Project-Based Learning (PBL) framework guided by the ADDIE model. Over 16 weeks, 137 undergraduates (2023 cohort) engaged in real-world projects such as carbon footprint optimization for urban rail transit. Quantitative pre/post assessments showed a 34% improvement in sustainability quantification skills ($p<0.01$), and qualitative analysis of policy briefs revealed that 89% of students demonstrated advanced ethical reasoning. Comparative analysis with 2022 cohort ($n=130$) taught under the traditional curriculum confirmed the effectiveness of the reform. The results indicate that digital-pedagogical integration significantly enhances students' ability to address sustainable transportation challenges, offering a replicable model for engineering education aligned with SDGs.

Keywords

Digital Intelligence, Transportation Economics, Project-Based Learning, Curriculum Reform, Sustainable Development Goals (SDGs)

Introduction

The transportation sector is undergoing dual pressures: digital transformation driven by AI, big data, and VR, and sustainability imperatives underscored by the UN SDGs (Xu & Li, 2025). Current transportation economics education, however, remains heavily focused on economic indicators, with limited integration of environmental and social dimensions, and inadequate training in digital tools such as VR, Python, and GIS (Zhou et al., 2025). This disconnect undermines graduates' readiness to address real-world sustainability challenges.

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This study addresses these gaps by reforming the Transportation Economics and Analysis course through the integration of digital intelligence tools within a PBL framework. The reform aims to enhance students' ability to apply economic-social-environmental (ESE) analysis to real transportation problems, thereby contributing to both educational innovation and sustainable transport development (Chen, 2025). The paper outlines the design, implementation, and outcomes of the reform, highlighting its implications for curriculum design and sustainability education (UNESCO, 2017).

Methodology

Participants, Design, and Data Analysis

This study adopted a comparative approach between two cohorts. The experimental group consisted of 137 undergraduate students (the 2023 cohort) enrolled in the Transportation Economics and Analysis course. The control group was the 2022 cohort (n=130), which received traditional lecture-based instruction. The course for the 2023 cohort was redesigned following the ADDIE instructional model, with Project-Based Learning (PBL) as the core pedagogy. Students worked in groups on real-world projects, such as optimizing the carbon footprint of urban rail systems. The integrated digital tools included VR simulations for policy impact visualization, Python for carbon footprint modeling and optimization, SPSS for statistical analysis, GIS for spatial equity assessment, and Tableau for data visualization within a blended online learning platform (Li et al., 2022).

Quantitative data were collected through pre- and post-course tests to measure the improvement in sustainability quantification skills. Qualitative data were derived from PBL project reports and ethical debates. To evaluate the reform's effectiveness, paired t-tests were used to analyze pre/post differences within the 2023 cohort, and independent samples t-tests were employed to compare the final outcomes of the 2023 and 2022 cohorts. The systematic instructional design and implementation process, guided by the ADDIE model, is illustrated in Figure 1.

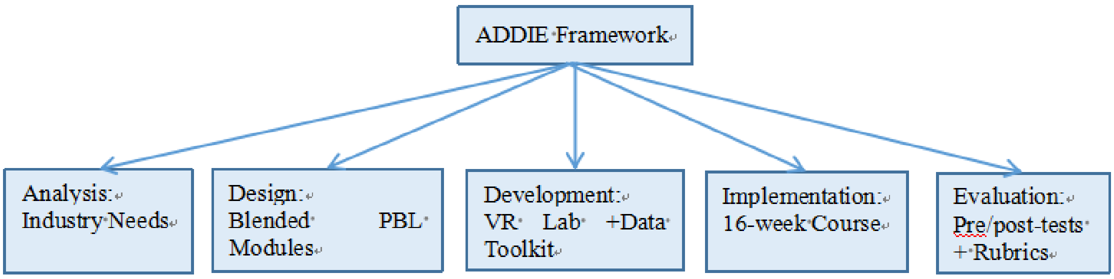

Figure 1: ADDIE Framework Implementation Process

Figure 1 provides a visual overview of the cyclical framework that guided the course reform, highlighting its five iterative phases.

Assessment Framework

A multidimensional assessment system was implemented to comprehensively evaluate student learning. The system combined process evaluation (70%) and outcome evaluation (30%), with specific criteria and weights detailed in Table 1. Process evaluation tracked online learning progress, participation in discussions and exercises, and offline attendance and engagement.

Outcome evaluation primarily focused on the final PBL project presentation, assessing the depth of economic-social-environmental (ESE) analysis, the sustainability of proposed solutions, and ethical considerations. To ensure fairness and objectivity, multiple evaluators were involved, with key components assessed by both the instructor and peers. The same core outcome criteria were applied to both cohorts for comparative purposes.

Table 1. Multidimensional Assessment Criteria

Evaluation method			Evaluation content and weight	Evaluation subject and weight	Appraisal ratio	Total evaluation score
Learning Record	Process evaluation	On-line	Learning Progress (30%)	Teacher100%	20%	100%
			Estimation（10%）	Teacher 50% Students 50%		
			Discussion replies (with sustainability and ethical discourse, 20%)	Teacher50% Students50%		
			Average score on tests (40%)	Teacher100%		
		Below-the-line	Attendance（5%）	Teacher100%	50%	
			Level of participation (40%)	Teacher50% Students50%		
			Classroom exercise (40%)	Teacher50% Students50%		
			Classroom performance (Initiative and contribution in discussions on sustainable issues, group inquiry, 15%.)	Teacher100%		
	Evaluation of results	Below-the-line	Presentation of work (focus on evaluating depth of ESE analysis, program sustainability, ethical considerations, 100%)	Teacher50% Students50%	30%	

As outlined in Table 1, the assessment combined process evaluation, which tracked ongoing engagement, with outcome evaluation, focusing on the final project's comprehensive quality.

This comprehensive instructional design provided a solid foundation for evaluating the reform's effectiveness.

Results and Discussion

The comparative analysis between 2023 cohort (experimental group) and 2022 cohort (control group) demonstrated the significant impact of the curriculum reform, with results structured around core competencies and contributions to SDGs.

Quantitative and Qualitative Skill Enhancement

Quantitative assessments revealed a statistically significant 34% average improvement in sustainability quantification skills within 2023 cohort ($p<0.01$), starkly contrasting with the minimal change observed in 2022 cohort. Mastery of digital tools for ESE analysis reached 92% in the experimental group, compared to 45% proficiency in basic tools within the control group. Qualitatively, analysis of PBL outputs showed 89% of 2023 cohort demonstrated advanced ethical decision-making—such as designing GIS-based equitable fare strategies—more than doubling the 41% rate in the traditional cohort. This aligns with Hussain et al. (2025) emphasis on moving beyond theory to practical tool application and ethical reasoning for effective sustainability planning, a goal met through the PBL approach.

Contribution to Sustainable Development Goals

The integration of digital tools enabled direct engagement with SDGs. For instance, Python-based optimization models developed by students achieved an average simulated carbon reduction of 23% in urban rail projects (SDG 13). Furthermore, VR simulations allowed 78% of groups to effectively visualize and analyze the economic-social-environmental trade-offs of policies like congestion pricing (SDGs 3 & 11). These data-driven, actionable outcomes exceed the descriptive nature of traditional curriculum outputs, effectively bridging the academia-industry gap noted by Xi (2025).

Limitations and Future Directions

A key limitation was the accessibility of VR for a minority of students (12%) with limited internet resources. Future iterations will adopt web-based simulations to ensure equity. The study's single-institution context also suggests a need for cross-cultural validation through international partnerships, applying the framework to challenges like zero-carbon freight to enhance generalizability.

Conclusion

This study validates the effectiveness of integrating digital intelligence (VR, Python, GIS) within an ADDIE-PBL framework to reform transportation economics education. The reform successfully cultivated students' dual literacy in sustainability and digital analysis, as evidenced by significant improvements in quantitative skills (34%, $p < 0.01$), tool mastery (92%), and ethical reasoning (89%). The findings demonstrate a replicable model for aligning engineering education with Sustainable Development Goals, directly addressing the gap between traditional curricula and the complex demands of the sustainable transportation sector.

The framework provides a structured approach for educators to bridge the academia-industry gap, equipping graduates with the practical competencies to tackle challenges like carbon footprint optimization. Future work will focus on enhancing the model's accessibility through web-based simulations and expanding its scope via cross-cultural partnerships to address emerging areas such as zero-carbon freight, further solidifying the role of education in driving sustainable transport transitions.

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