



## Improving Traffic Safety Through Innovation: A Systematic Review of Technology-Enhanced Education for Novice Drivers with Implications for LMICs

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### ARTICLE INFO

Manuscript Received: 20 Apr, 2025

Revised: 10 Jan, 2026

Accepted: 03 May, 2026

Date of publication: 01 Jul, 2026

Volume: 6

Issue: 2

DOI: [10.56338/jphp.v6i2.7317](https://doi.org/10.56338/jphp.v6i2.7317)

### KEYWORDS

Road Safety Education;  
Novice Drivers;  
Gamification;  
Virtual Reality;  
Behavioral Change

### ABSTRACT

**Introduction:** Road traffic accidents remain a major global public health challenge, disproportionately affecting low- and middle-income countries (LMICs), where fatality rates among novice drivers are particularly high. Despite this burden, most empirical research on road safety education has focused on high-income settings, leaving significant gaps in evidence relevant to LMIC contexts. This study aims to systematically review the effectiveness of technology-based interventions for road safety education among novice drivers and to examine their behavioral outcomes, theoretical foundations, and contextual relevance in LMICs.

**Methods:** A systematic literature review was conducted in accordance with PRISMA 2020 guidelines. Peer-reviewed journal articles published between 2015 and 2025 were retrieved from the Scopus database using predefined search terms related to road safety education, novice drivers, and digital or technology-enhanced interventions. After screening and eligibility assessment, 47 empirical studies were included for synthesis. Data were extracted on intervention type, theoretical framework, geographic setting, and behavioral outcomes, and analyzed using descriptive, thematic, and network-based approaches.

**Results:** The findings indicate that technology-enhanced interventions, including gamification, virtual reality, mobile applications, telematics, and artificial intelligence, are generally associated with improved learner engagement, enhanced hazard perception, safer driving behavior, increased helmet use, and reduced traffic violations among novice drivers. However, most studies lack explicit theoretical grounding, rely on short-term outcome measures, and are concentrated in high-income settings, limiting generalizability to low- and middle-income contexts.

**Conclusion:** This review highlights the need for theory-informed, culturally sensitive, and context-responsive road safety education strategies that integrate behavioral science with digital innovation. Strengthening longitudinal evaluation and expanding research in underrepresented regions are essential to inform effective policy and scalable intervention design.

**Publisher:** Pusat Pengembangan Teknologi Informasi dan Jurnal Universitas Muhammadiyah Palu

## INTRODUCTION

Road traffic accidents remain a significant global public health concern, disproportionately affecting low- and middle-income countries (LMICs), where approximately 93% of the world's 1.35 million annual road traffic deaths occur (1,2). While numerous studies concentrate on high-income nations, novice drivers in low- and middle-income countries (LMICs), especially adolescents and young adults, exhibit heightened vulnerability due to a confluence of inexperience, diminished risk perception, and insufficient safety education (3,4). Since road safety is a complex issue influenced by factors such as roads, laws, behavior, and education, efforts to reduce road traffic injuries in low- and middle-income countries need to address all these factors with well-researched strategies.

RTIs have a heavy socioeconomic burden, especially in LMICs, where road infrastructure is substandard, and road regulations are often ineffectively enforced (5,6). Such circumstances make things even worse, as young drivers lack experience and training, which frequently leads to a high rate of accidents. Moreover, there are cultural attitudes that tolerate risky behaviors, such as speeding and driving under the influence, which also contribute to the challenge (7,8). To address such complex risk factors, interventions such as road safety education (RSE) have been widely embraced as a necessary measure to equip novice drivers with the knowledge, skills, and attitudes to adopt safe driving behavior (9,10).

The conventional methods of RSE in LMICs tend to emphasize theoretical education rather than practice. Although these approaches have proved effective to some degree in raising awareness (11,12), it is argued that increases in knowledge alone cannot lead to long-term behavioral change. Moreover, traditional RSE programs also have issues with appropriateness for the diverse cultural and socioeconomic backgrounds of learners, limiting their applicability and usability (13,14). These difficulties are also complicated by infrastructure bottlenecks and the insufficiency of human resources, which, in the end, lead to a reduction in the extent of programs and their long-term effectiveness (15).

Technological innovations offer new opportunities to transform RSE, making it more engaging, accessible, and adaptive. Emerging methods include gamification, virtual reality (VR), artificial intelligence (AI), and telematics systems, which enable interactive and personalized learning experiences (16–18). Empirical evidence suggests that these tools are associated with higher levels of cognitive engagement and learning retention among novice drivers, largely due to immersive environments and real-time feedback mechanisms (19,20). Moreover, AI-powered platforms can analyze driving behavior patterns and provide tailored interventions to correct risky practices (21,22).

Several theoretical models underpin the design of effective RSE interventions. The Theory of Planned Behavior (TPB) posits that attitudes, perceived behavioral control, and subjective norms influence behavioral intentions, providing a robust framework for predicting driving behavior (23,24). Similarly, the Protection Motivation Theory (PMT) and Social Cognitive Theory emphasize risk perception and observational learning, respectively, supporting the use of fear appeals and modeling in educational content (25,26). Despite the utility of these models, their application remains limited across the broader literature, with 78.7% of the reviewed studies failing to employ an explicit theoretical framework, particularly in LMICs (27,28).

Interestingly, studies in RSE exhibit significant gaps in research methodology and theory. There are few longitudinal studies, and little is known about the sustainability of educational effects (29). Most interventions are culturally insensitive and do not take into account cultural factors such as urban-rural variations, digital literacy, and socioeconomic status (7,30). Moreover, although diverse tools such as VR and gamification have been considered in high-income regions, their application and their potential in LMICs are understudied (31,32).

To achieve a deeper understanding of these gaps, an interdisciplinary approach, including newer theoretical insights such as the Technology Acceptance Model (TAM) and the Ecological Model, is necessary to address the relationship among individual, technology, and environmental determinants of road safety behavior (3,33). Moreover, the planning, execution, and assessment of contextually relevant RSE programs should be carried out through collaborative efforts among all players in the field, such as public health professionals, educators, technologists, and policymakers (34,35).

Given the growing need for coherent road safety solutions that meet the needs of LMICs, this systematic literature review (SLR) critically evaluates technological developments in RSE that could be offered to new drivers. This study is based on the analysis of 47 peer-reviewed articles published in 2015-2025 and indexed in the Scopus database, which included data on intervention types, theoretical and geographical backgrounds, and behavioral

outcomes. Although the majority of the studies included in the review were conducted in high-income countries, the review also identifies implications and gaps applicable to LMIC contexts.

The objectives of this study are threefold: first, to synthesize existing evidence on the effectiveness of digital and technology-based RSE interventions; second, to assess the extent of theoretical integration in current RSE research; and third, to propose a conceptual model for future investigations and policy formulation. By situating these findings within the broader discourse on public health and safety, this review contributes to the development of adaptive, scalable, and culturally responsive solutions to improve road-safety outcomes among novice drivers in LMICs.

This review underscores the urgent need to innovate road safety education by integrating technological, theoretical, and contextual approaches. As countries strive to reduce RTIs and promote safer road behaviors, understanding the mechanisms and conditions under which educational interventions succeed is vital. This research seeks to support both academic studies and real-world applications by offering practical guidance to improve the effectiveness and long-term success of road safety education programs, particularly in resource-limited areas.

## **METHOD**

### **Research Approach**

The study will use a systematic literature review (SLR) to assess the effectiveness of technology-based interventions in road safety education (RSE) for novice drivers, particularly their applicability in new low- and middle-income countries (LMICs). The SLR method is suitable for addressing scattered empirical results and research gaps, and for producing evidence-based theoretical and practical suggestions on the structure of interventions and the policy orientation. This review protocol is written according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA 2020) to provide methodological transparency, replicability, and rigor (36). Moreover, several important aspects of the SPAR-4-SLR framework were added to enhance the organization and reporting of the review process (37).

The process followed a systematic nature in that it was divided into six steps, including (1) identification of keywords, inclusion and exclusion criteria and review boundaries, (2) searching the database and the initial retrieval of records, (3) de-duplication and relevance screening, (4) screening of titles, abstracts and keywords, (5) full-text assessment and extraction of structured data and (6) analytical synthesis, which involved an examination. Watase UAKE was operationalized as a collaborative review-management tool to handle record, screening coordination, tagging and coding, and extraction form management, similar to existing tools like Rayyan or other AI-assisted screening tools. Notably, Watase UAKE is not a specific methodological framework, as it was used only as a tool to facilitate the implementation and documentation of PRISMA- and SPAR-4-SLR-guided methods.

To further improve clarity and reproducibility, the updated manuscript now includes (a) full database query syntax, (b) comprehensive screening and data-extraction logs, and (c) an audit trail export in the Supplementary Materials. There are also publicly available institutional descriptions of Watase UAKE that explain its purpose as a PRISMA- and SPAR-4-SLR-supportive platform, ensuring that the methodological underpinnings of the review are grounded in the existing and popular systematic review criteria.

### **Literature Search and Selection Criteria**

The literature search was conducted using the Scopus database, selected for its broad coverage of peer-reviewed journals and robust indexing quality (38–40). To ensure full replicability, we provide the complete Scopus query syntax using the TITLE-ABS-KEY field and apply Boolean operators (AND) to link the core constructs. Because Scopus does not employ a controlled-vocabulary thesaurus, the search strategy relied on explicit synonym mapping for (i) road safety education (e.g., "road safety education" OR "driver education" OR "traffic safety education"), (ii) novice drivers (e.g., "novice driver" OR "young driver" OR adolescent\* OR teenager\* OR "young adult\*"), and (iii) technology-enhanced modalities (e.g., gamif OR "serious game" OR "virtual reality" OR VR OR "mobile learning" OR app\* OR telematic\* OR "artificial intelligence" OR AI OR digital). The primary thematic anchor, "road safety education," was retained to maintain alignment with prior global SLR procedures and ensure consistency with earlier review methodologies (41).

Searches were restricted using Scopus filters to capture contemporary evidence: publication years 2015–2025, document type: journal articles, source type: journals, and language: English. Studies were included if they:

(1) focused on novice drivers (adolescents, teenagers, and young adults); (2) evaluated technology-based RSE interventions (e.g., digital platforms, gamification, VR, mobile learning, telematics); (3) reported outcomes related to behavior, knowledge, attitudes, risk perception, or safety compliance; and (4) were published in English. Studies were excluded if they: (1) lacked empirical evidence (e.g., conceptual papers without evaluation data); (2) targeted non-novice populations; (3) were published before 2015; or (4) were not peer-reviewed scholarly articles (11).

### Article Screening Process

The screening process followed the four-stage PRISMA model: Identification, Screening, Eligibility, and Inclusion. Initially, 600 records were identified. After removing 47 duplicates, 553 records remained. Automated screening filters based on publication year and relevance excluded 205 records. Subsequently, abstract and full-text assessment removed an additional 240 studies. In the eligibility stage, 101 full-text articles were examined in detail, and 54 papers were excluded due to inaccessible full texts or misalignment with the review objectives. Finally, 47 studies were retained for in-depth synthesis and analysis.

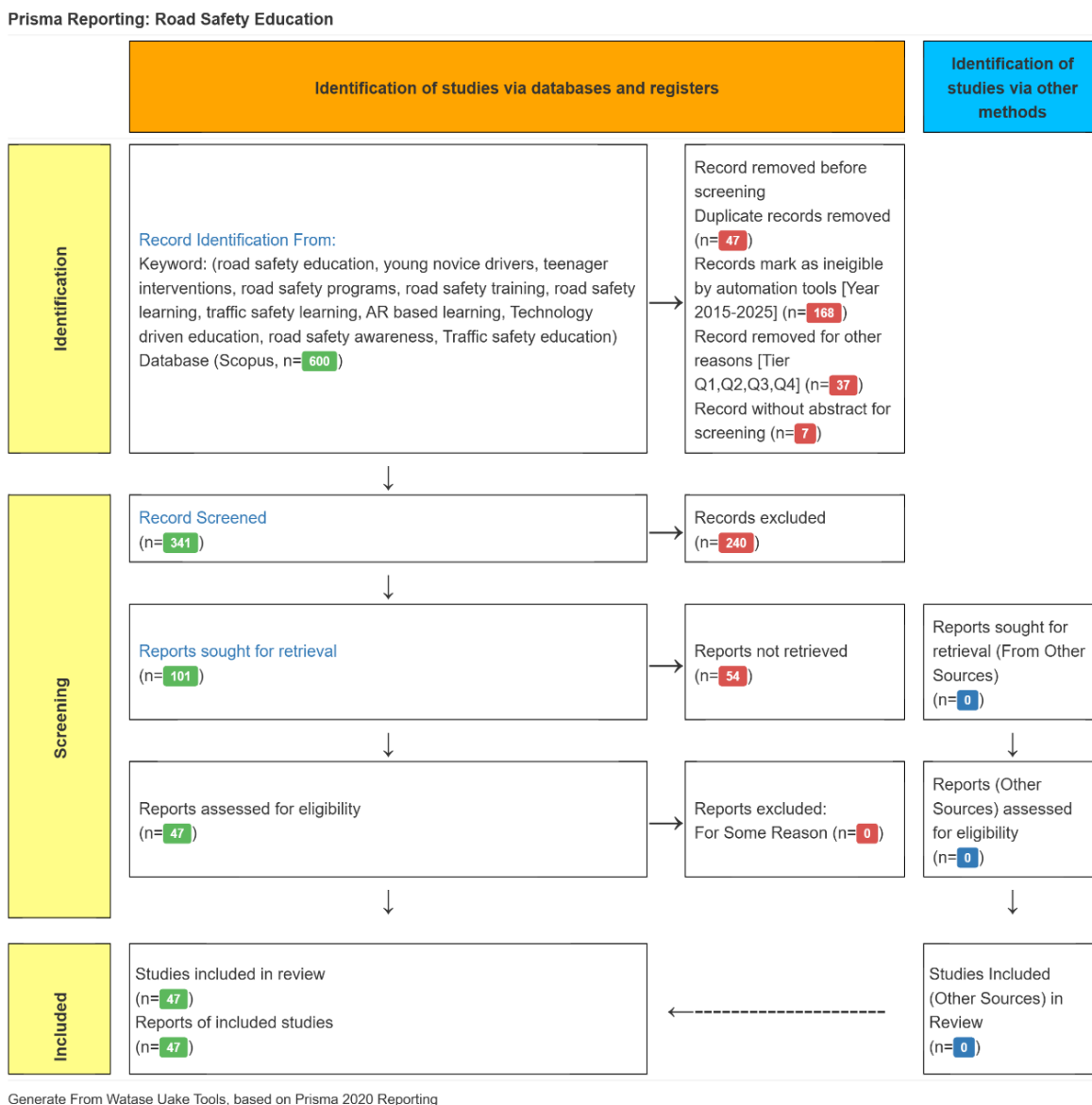


Figure 1. Presents the PRISMA flow diagram to document the screening process and selection decisions.

## **Population and Sample**

In an SLR, the population is defined as the body of scholarly literature addressing the research topic rather than individual participants. The sample for this review comprises 47 peer-reviewed journal articles indexed in Scopus, representing diverse international contexts. These studies specifically investigate technology-based road safety education interventions targeting novice driver populations within LMIC settings, reflecting varied socio-cultural characteristics and differing levels of technological readiness.

## **Research Location**

As a review study, this research is not restricted to a physical location. Instead, geographic distribution is represented through the country settings of the selected studies. The reviewed literature spans multiple countries, including Belgium, Iran, Spain, and other LMIC contexts. The country distribution is visualized in **Figure 3** (Country of Research), demonstrating regional patterns, priorities, and disparities in technology adoption for road safety education (7,42).

## **Research Instruments**

A standardized data extraction form was developed to ensure consistent analysis across studies. Key variables included: (1) study design and methodology, (2) demographic characteristics of the target population, (3) type of technology/intervention (e.g., gamification, VR, mobile apps, telematics), (4) intervention duration and delivery method, (5) theoretical frameworks employed, and (6) outcomes measured and reported effect direction. Qualitative dimensions such as engagement, feasibility, cultural adaptation, and implementation barriers were also recorded to support contextual interpretation (8,9).

## **Data Collection Techniques**

Full-text articles were systematically reviewed, and all relevant variables were extracted using a standardized form. Each included study was evaluated for methodological quality using the AMSTAR 2 critical appraisal tool, which supports structured assessment of review and intervention reporting standards (43). Descriptive statistical techniques were applied to summarize publication trends, geographic distribution, intervention categories, and keyword frequency. Thematic concentration and terminological patterns were visualized through outputs such as **Figure 2** (Publication Trends) and **Figure 4** (Keyword Word Cloud).

## **Data Analysis Procedures**

Data analysis was conducted using both quantitative and qualitative synthesis techniques. Quantitative procedures involved frequency and distribution analyses of intervention types, theoretical models, outcomes, and geographic representation. Where outcome metrics were sufficiently comparable across studies, selective meta-analytic procedures were applied to compute effect sizes (44). Qualitative synthesis employed thematic analysis using the Concept Matrix method (45), allowing systematic categorization of recurring themes such as engagement mechanisms, behavioral change pathways, and contextual barriers. To enhance explanatory depth, hypothesis network analysis was conducted to map variable interrelationships and identify dominant causal logics across the literature (46). Network outputs are presented in **Figure 8** (Network Analysis) and **Table 3** (Most Popular Hypothesis), highlighting hypothesized relationships such as the influence of RSE interventions on driving behavior, helmet compliance, and risk perception (47,48). Additional classifications were applied to examine theoretical and contextual patterns. The distribution of theory usage is summarized in **Figure 6** (Theory Classification) and **Table 2** (Theory Citation), while contextual distribution and research settings are described in **Figure 5** (Context Classification) and **Table 1** (Context Citation).

## **Reliability and Validity Measures**

To ensure reliability and consistency, data extraction and interpretation were cross-validated by multiple reviewers. Discrepancies in article inclusion and data coding were resolved through consensus discussions. The use of established frameworks such as PRISMA and AMSTAR 2 further enhances methodological rigor and reproducibility (49).

### Ethical Approval

As this research involves a systematic analysis of secondary, publicly available data, it does not require ethical approval from a research ethics committee. No human participants were involved, and no personal or sensitive data were collected. This aligns with ethical standards for non-interventional literature-based studies (50).

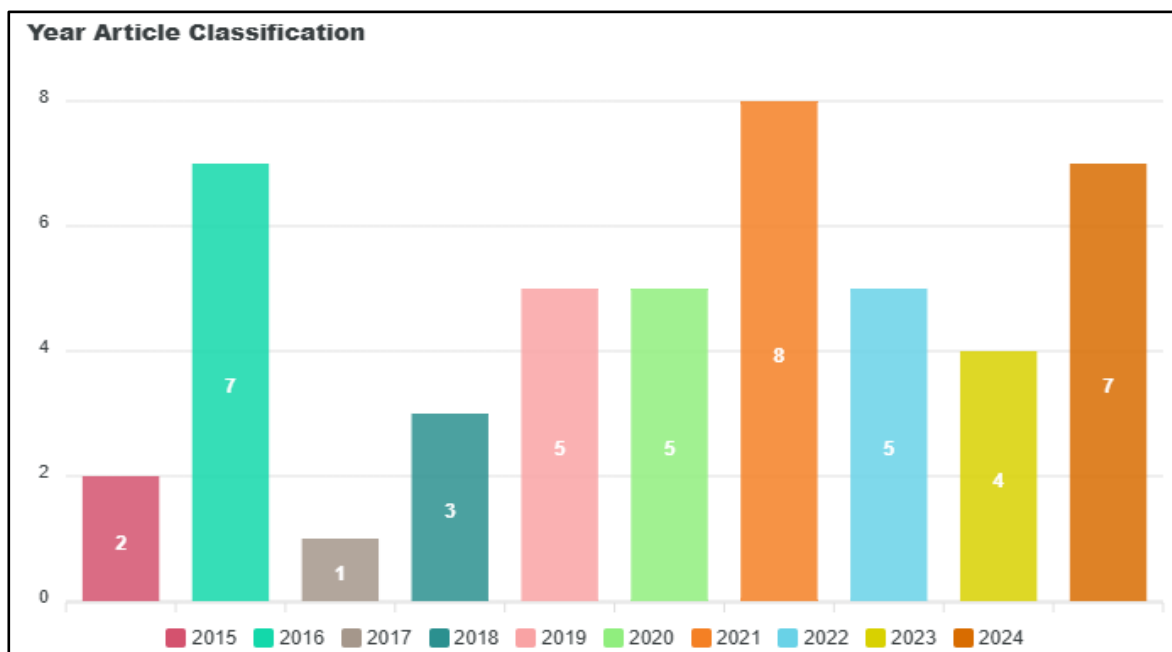
## RESULTS

### Overview of Selected Studies

This systematic literature review included 47 peer-reviewed journal articles published between 2015 and 2025, drawn from the Scopus database. These studies investigated road safety education (RSE) interventions aimed at novice drivers, with varying degrees of relevance to low- and middle-income country (LMIC) contexts. The articles varied in focus, methodology, geographical context, and theoretical foundation. Overall, the findings reflect increasing academic interest in integrating technological innovations such as gamification, virtual reality (VR), telematics, and artificial intelligence (AI) into RSE (19,20).

### Publication Trends and Geographic Distribution

As illustrated in **Figure 2**, the publication of RSE-related studies has steadily increased over the last decade, with notable peaks in 2019 and 2021, coinciding with advancements in immersive learning tools (20,51)



**Figure 2.** Publication of Article

The geographic distribution of studies, shown in **Figure 3**, highlights strong representation from Belgium, Iran, and Spain. While Belgium represents a high-income context, Iran and a limited number of other studies provide evidence from LMIC settings, indicating an overall imbalance in regional representation (7,42).



### Thematic Focus and Contextual Classification

Figure 5 provides a breakdown of the study's focus. Most studies addressed general road safety education (33 articles), followed by traffic safety programs (11 articles) and community-based interventions (3 articles). This distribution underscores the centrality of educational strategies in promoting behavior change among young road users (33).

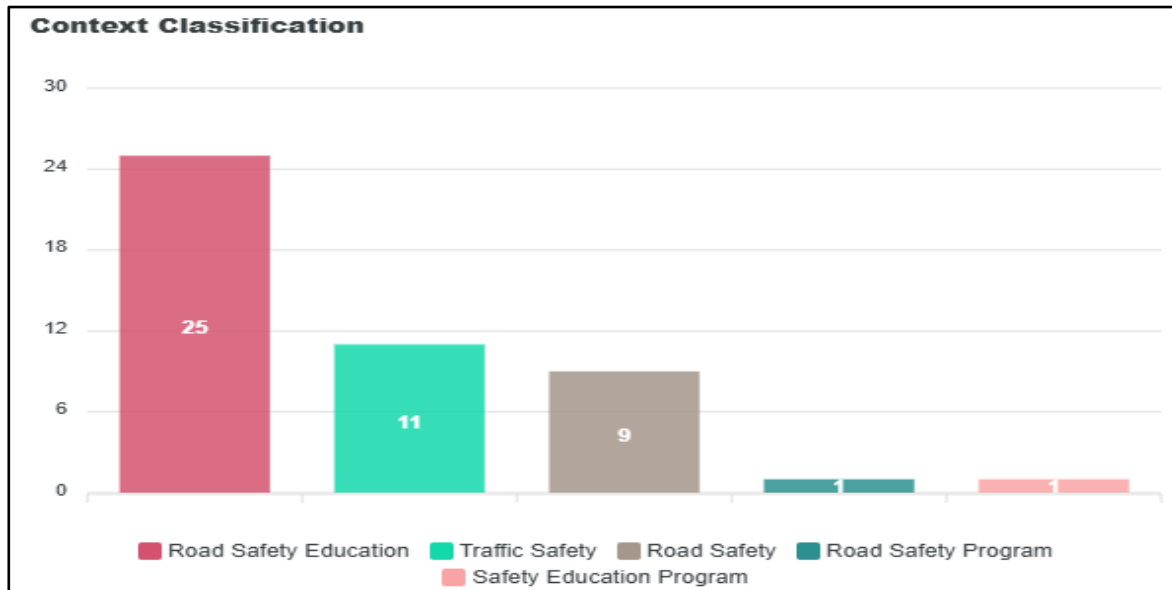


Figure 5. Context Classification

Table 1 Context Citation

No	Context	Citation	Total Articles
1	Road Safety Education	625	33
2	Traffic Safety	133	11
3	Road Safety	101	9
4	Road Safety Program	63	3
6	Safety Education Program	4	1

### Theoretical Frameworks

Among the reviewed studies, the Theory of Planned Behavior (TPB) emerged as the most widely used theoretical foundation, followed by the Protection Motivation Theory (PMT), Social Cognitive Theory (SCT), and the Technology Acceptance Model (TAM). Where applied, TPB was primarily used to structure interventions targeting attitudes toward safe driving, perceived behavioral control, and normative influences, while PMT-informed studies emphasized threat appraisal and coping appraisal through fear-based or risk-framing educational content. SCT-based interventions focused on observational learning and self-efficacy development, particularly through simulation and modeling approaches, whereas TAM was used to explain learner acceptance and continued use of digital RSE platforms. However, 78.7% of studies did not explicitly reference any theoretical model, indicating a significant theoretical gap, particularly in studies conducted in or claiming relevance to LMIC contexts (25,28). Further details regarding the distribution and citation frequency of these theoretical frameworks are provided in Figure 6. Theory Classification and Table 2. Theory Citation

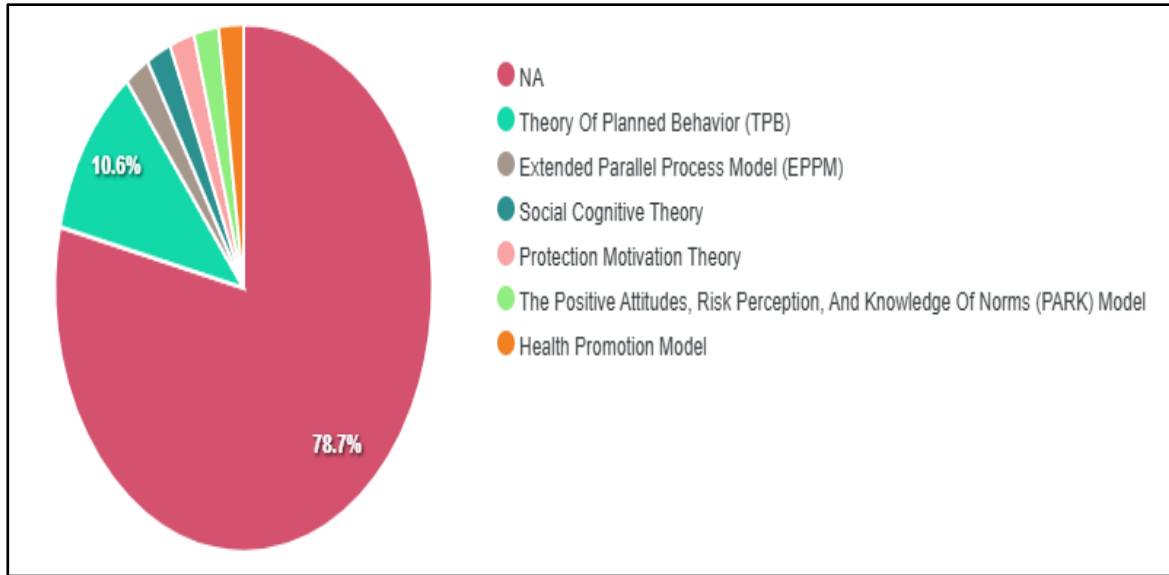


Figure 6. Theory Classification

Table 2. Theory Citation

No	Theory	Citation	Total Article	Authors
1	Theory Of Planned Behavior (TPB)	82	4	Lewis et al., 2021; Dalton et al., 2020; Riaz et al., 2019; Cuenen et al., 2016
2	Extended Parallel Process Model (EPPM)	16	1	Kennedy et al., 2018
3	Protection Motivation Theory	116	1	Alonso et al., 2018
4	Social Cognitive Theory	14	1	Zhang et al., 2022
5	The Positive Attitudes, Risk Perception, And Knowledge of Norms (PARK) Model	14	1	Alonso et al., 2020

**Intervention Types and Technological Tools**

The majority of interventions used digital tools to improve road safety behaviors. Gamified learning environments, such as educational video games and interactive applications, were prominently featured. VR-based simulations allowed novice drivers to practice in risk-free scenarios (16,17). AI and telematics tools provided real-time feedback and behavior monitoring (18,21). These technology-based interventions were associated with higher engagement levels and improved learning retention compared to traditional methods (Khan et al., 2021). Moreover, studies integrating social media platforms for disseminating educational content also reported increased accessibility and community involvement (32).

**Hypotheses Tested and Behavioral Outcomes**

Table 3 summarizes the most frequently tested hypotheses. The predominant hypothesis examined was the impact of road safety education on driving behavior (16 studies), followed by the relationship between perceived safety and helmet use, and the effectiveness of road safety training in reducing traffic violations (47,48).

**Table 3.** Most Popular Hypothesis

No	Independent	Dependent	Count	Authors
1	Road Safety Education	Driving Behavior	16	Br?tucu et al., 2016; Mark and Al-Mansour, 2020; Zainafree et al., 2022; Nawaz et al., 2024
2	Perceived Safety	Helmet Usage	10	Twisk et al., 2015; Freydier et al., 2016; Purcell and Romijn, 2017; Zare et al., 2019; Gifty et al., 2021; ?eibokait? et al., 2022; Zhang et al., 2022; Safarov et al., 2023; Akuh et al., 2023; Yang and Yi, 2024
3	Road Safety Training	Traffic Violations	10	Zimmerman et al., 2015; Cuenen et al., 2016; Kennedy et al., 2018; Hawley et al., 2018; Mart?n-delosReyes et al., 2019; Topol?ek et al., 2019; Bakhtari et al., 2020; Yu and Tsai, 2021; Gounaridou et al., 2021; Pham et al., 2024
4	Weather Condition	Helmet Usage	10	Twisk et al., 2015; Freydier et al., 2016; Purcell and Romijn, 2017; Zare et al., 2019; Gifty et al., 2021; ?eibokait? et al., 2022; Zhang et al., 2022; Safarov et al., 2023; Akuh et al., 2023; Yang and Yi, 2024
5	Road Safety Campaign	Driver Speed Reduction	5	Alonso et al., 2020; Alonso et al., 2021; Zulkifli et al., 2021; Masilamani et al., 2022; Desjardins and Lavall?ere, 2023
6	Educational Intervention	Road Safety Knowledge	4	Dalton et al., 2020; Mark and Al-Mansour, 2020; Lewis et al., 2021; Chou et al., 2022
7	Fear Messaging	Behavioral Intentions	4	Dalton et al., 2020; Mark and Al-Mansour, 2020; Lewis et al., 2021; Chou et al., 2022
8	Dui Workshop	Behavioral Change	2	Riaz et al., 2019
9	Gamification	Learning Engagement	2	Riaz et al., 2019
10	Perceived Ease of Use, Satisfaction Perceived Usefulness, and Enjoyment		2	Zulkifli et al., 2021

Behavioral outcomes primarily included improved driving behavior, increased use of safety gear (e.g., helmets), and reductions in violations. Dependent variables in most studies focused on measurable behavioral changes, while independent variables included the nature of the intervention and demographic factors.

**Variable Distribution**

**Figure 7** presents the frequency of variables used in the studies. The most commonly explored variables were road safety education (19 studies), driving behavior (17 studies), and helmet usage (11 studies). Less frequently examined variables, such as fear messaging and gamification, highlight emerging trends in behavioral influence strategies.



**Evidence Gaps and Moderating Variables**

**Table 4** identifies contradictory evidence across several studies. While some interventions reported strong effects, others found limited or no behavioral changes, particularly in rural settings. Moderating factors such as age, gender, socioeconomic background, and urban versus rural residence were often underexplored (4,30).

**Table 4.** Contradictory Evidence Gap - Explore Moderation

No	IV	DV	Moderation	Article	High	Low	Explore
1	Road Safety Education	Driving Behavior		16		18	Moderation
2	Perceived Safety	Helmet Usage		10	10		
3	Road Safety Training	Traffic Violations		10		10	Moderation
4	Weather Condition	Helmet Usage		10		10	Moderation
5	Road Safety Campaign	Driver Speed Reduction		5		5	Moderation
6	Educational Intervention	Road Safety Knowledge		4		4	Moderation
7	Fear Messaging	Behavioral Intentions		4		4	Moderation
8	Dui Workshop	Behavioral Change		2	2		
9	Gamification	Learning Engagement		2		2	Moderation
10	Perceived Ease of Use, Perceived Usefulness, and Enjoyment	Satisfaction		2		2	Moderation

**Emerging Theoretical and Practical Gaps**

The review revealed limited application of ecological and system-level frameworks such as the Social-Ecological Model and the Diffusion of Innovations Theory. Their absence limits understanding of the multi-level influences on driver behavior. Only a few studies applied models such as the Extended Parallel Process Model or Health Promotion Model (3,53).

**Table 5.** Theoretical Gap

No	Theory	Count
1	Extended Parallel Process Model (EPPM)	1
2	Health Promotion Model	1
3	NA	37
4	Protection Motivation Theory	1
5	Social Cognitive Theory	1
6	The Positive Attitudes, Risk Perception, And Knowledge of Norms (PARK) Model	1
7	Theory Of Planned Behavior	5

**Proposed Conceptual Model**

**Figure 9** presents a conceptual model synthesizing key findings. It illustrates the central role of road safety education in shaping driving behavior through mediating variables such as road risky behavior, social media-based education, and contextual influences. Supporting theories include TPB, PMT, and SCT, with ecological and technological frameworks proposed for future integration.

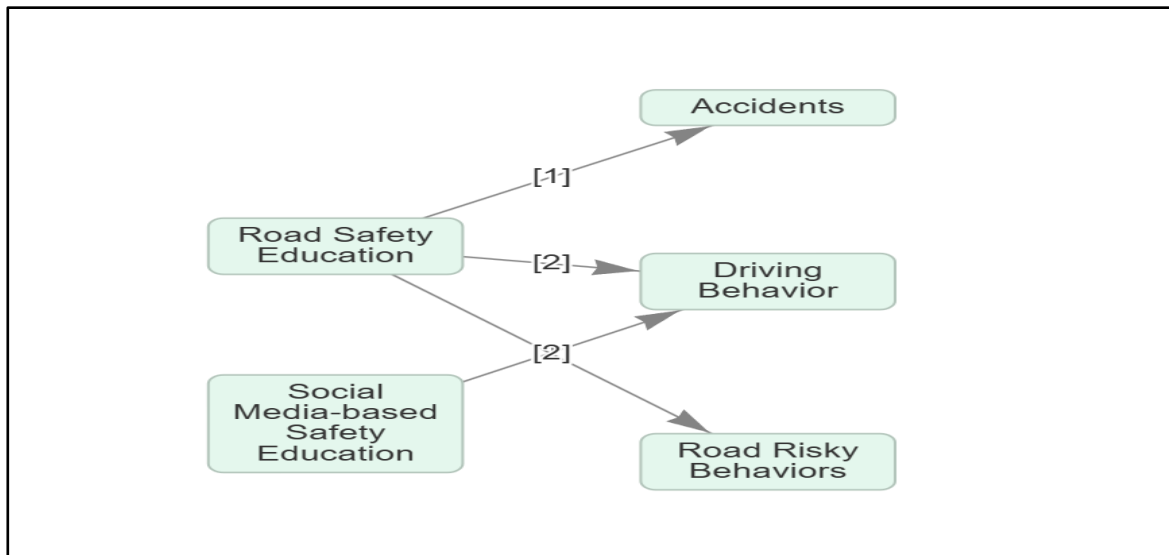


Figure 9. Model Suggestion

## DISCUSSION

This was a systematic literature review (SLR) aimed at evaluating the development and efficacy of technological applications in road safety education (RSE) for novice drivers, particularly their implications for low- and middle-income countries (LMICs). The review, as discussed below, interprets the findings in the broader context of public health and behavioral science, explores their theoretical and practical implications, compares them with past studies, acknowledges the study's methodological shortcomings, and outlines future research directions.

### Interpretation of Key Findings

The review has shown that digital transformation, in the form of gamification, virtual reality (VR), telematics, and artificial intelligence (AI), is being employed within the context of RSE programs. The main objectives of these technologies are to increase learner engagement, advance hazard perception, and reinforce safe driving behaviors through immersive, interactive experiences (18–20). The strength of evidence, however, differed across studies, and effects were context-dependent. Gamified interventions based on serious games are consistently successful in terms of knowledge retention and learner satisfaction, especially among adolescents and young adults (16,54).

Through feedback and experiential learning, such technological tools aid behavior change, which is constrained by traditional, didactic methods that tend to be less interactive and less adaptable to context (14,15). Additionally, social media and mobile-based tools appear useful for helping participants learn among themselves and through the community, particularly when resources are limited (9,32).

The analysis also identified clear thematic priorities. The most frequently studied variables were driving behavior, safety education, and helmet usage (33). However, a closer examination reveals notable region-specific gaps: the research of high-income countries has been disproportionately centered on more advanced simulation technologies and telematics-based feedback, and the research on low- and middle-income regions, especially in sub-Saharan Africa, Southeast Asia, and some parts of Latin America, is limited and, in any case, concentrates on less advanced educational or campaign. Additionally, in line with the behavioral theory of science, the most proven hypotheses were those that centered on the effects of education on driving behavior and on minimizing violations (47,48).

### Theoretical and Practical Implications

An important theoretical implication of this review is the inadequate use of established behavioral frameworks. A majority of the studies (more than 75 percent) did not use any theoretical model, especially those that assert LMIC applicability (25,28). This restricts the explanatory and predictive ability of the interventions. The

incorporation of theories such as the Social Cognitive Theory (26), the Technology Acceptance Model (33), and the Diffusion of Innovations Theory (53) may offer a more holistic approach to user engagement, adoption, and sustained behavior change.

In practice, this review substantiates the idea that technology-enabled interventions can address the challenges of scale and access in LMICs. VR simulations and mobile-based telematics are efficient not only in boosting learning outcomes but also in their nature, which enables personalization and real-time feedback, a prerequisite for young or inexperienced drivers with little road experience (18,21).

Nonetheless, its implementation depends on socio-cultural adaptability, digital literacy, and infrastructure readiness. Although gamification and VR have potential in well-resourced settings, their applicability in rural or poorly connected areas remains unclear (27,31). The programs should be culturally sensitive, linguistically relevant, and technologically viable.

### **Comparison with Previous Studies**

This review supports previous findings indicating that behavior-change theory-based educational interventions can be used to prevent risky driving behaviors (4,10). Furthermore, the review supports the view that adolescents and young adults are the primary beneficiaries of learning in an interactive, context-sensitive, and technology-enhanced learning environment (20,54). Other past meta-analyses have highlighted the usefulness of simulations and serious games in health and safety learning (29,51). The results of this review further support the idea that individual feedback via AI and telematics is an effective way to enhance driving performance, aligning with recent findings in traffic psychology and vehicle safety (18,22).

However, there are certain contradictions. Some studies also found limited behavior change, regardless of the intervention's level of sophistication, especially when cultural, demographic, or infrastructural variables were not considered (30,55). This underscores the need to create simultaneous, technology-enabled, context-based interventions.

### **Limitations of the Current Literature**

Although the number of studies continues to increase, several limitations remain. To begin with, longitudinal studies evaluating the long-term effects of RSE interventions are lacking tremendously. The majority of available studies are short-term and fail to reflect changes in behavior over a long period or the risk of relapsing into risky behavior (3,29). Secondly, there is a skewed geographic representation, with less research in sub-Saharan Africa, Southeast Asia, and Latin America. This disproportion limits the robustness of generalization and obscures region-specific difficulties (6,13).

Thirdly, there is an inconsistent application of theoretical underpinnings. Although TPB and PMT are predominant, newer or supplemental models, such as the Social-Ecological Model and the Extended Parallel Process Model, are still underused (8,56). The lack of theoretical diversity makes it difficult to develop multidimensional interventions that account for personal, social, and environmental factors that drive behavior.

Fourthly, cross-study comparability is limited by methodological differences. Depending on the studies, they use different designs, sample sizes, and outcome measures, making it challenging to combine results or perform high-quality meta-analyses (43,44).

### **Recommendations for Future Research**

These results suggest several research directions. First, longitudinal studies are urgently needed to determine long-term behavioral outcomes of RSE interventions. Such studies must assess the long-term maintenance of the observed effects and the occurrence of relapses into unsafe driving behaviors, as proposed by (29). Second, it is imperative to expand geographically. To explore more underrepresented LMIC areas, particularly sub-Saharan Africa and Southeast Asia, and to represent a wider range of cultural and infrastructural contexts, more studies are needed, as highlighted by (30).

Third, theoretical integration should be the priority. To enhance the design and explanatory strength of RSE interventions, researchers are advised to expand the use of the theoretical framework by using models like the Theory of Planned Behavior (TPB), Protection Motivation Theory (PMT), Social Cognitive Theory (SCT), Technology Acceptance Model (TAM), and ecological perspectives (26,33). Fourth, it is essential to adapt to technology. Future

research should determine the viability, availability, and cultural suitability of high-tech devices such as VR and AI, especially in resource-poor areas. Effective design and implementation can be informed by pilot testing and local needs assessment (31).

Fifth, the use of mixed methods and participatory methods is worthy. The integration of quantitative and qualitative approaches could yield deeper insights into learners' experiences, program flexibility, and implementation issues (34). Sixth, RSE programs must be actively involved in the communities. The inclusion of parents, educators, and community leaders can help make programs more relevant, build trust, and expand the effectiveness of outreach (7,42).

Seventh, collaboration in policies must be enhanced. Establishing collaborations with policymakers will ensure that RSE interventions meet national road safety objectives and align with education systems, and that they can be supported and scaled by the institutions (2). Lastly, standardized measures need to be developed and adopted. These instruments can enhance the measurement of intervention outcomes and improve conformity and comparability across cultural and geographic settings (10).

## **CONCLUSION**

This paper examined how technological innovations can be integrated effectively into educating novice drivers on road safety, with a special focus on their applicability in low- and middle-income countries (LMICs). It evaluated the role of such tools as gamification, virtual reality, artificial intelligence, and telematics in behavioral change. The results show that these innovations are mostly related to enhanced learner engagement, perceptions of hazards, and knowledge retention, and that the world is moving towards the use of immersive, personalized learning experiences. It is worth noting that the study identified missing theoretical integration, limited longitudinal studies, and the underrepresentation of selected regions, such as sub-Saharan Africa, Southeast Asia, and Latin America, as key gaps. Such findings demonstrate the significance of context-sensitive, interdisciplinary, and theory-based design and implementation of road safety education, and that integrating digital tools and behavioral models can improve the coverage and effectiveness of interventions. Although this paper gives important information on the changing nature of road safety education, some limitations must be mentioned, including the inconsistency in the quality of research, imbalance in the outcome measurements, and geographic clustering of research. Future studies should aim to assess the long-term effects, expand the geographic range, and apply untapped theoretical models, which may yield better insights into effective educational measures and global public health and road-safety policies.

## **AUTHOR'S CONTRIBUTION STATEMENT**

All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

## **CONFLICTS OF INTEREST**

No conflicts of Interest.

## **DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS**

During the preparation of this work, the authors used ChatGPT to enhance the clarity of the writing. After using the tool, they reviewed the output to ensure the content's accuracy and integrity. The authors acknowledge that while ChatGPT assisted in improving the writing, the final responsibility for the content lies with them.

## **ACKNOWLEDGMENTS**

We want to express our gratitude to the Faculty of Public Health at Mulawarman University for its financial support.

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