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Research Article

Evaluating game-based learning for driving ethics awareness using the technology acceptance model: a study in the Malaysian context

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Abstract
The increasing complexity of driving scenarios, particularly with the emergence of automated vehicles, necessitates a comprehensive understanding of driving ethics among new drivers. This paper explores the use of game-based learning (GBL) as an innovative approach to educate and raise awareness of ethical driving practices in Malaysia. By employing the technology acceptance model (TAM), the study evaluates user acceptance of the e-Driver application, focusing on key dimensions such as perceived usefulness (PU), ease of use, and user satisfaction. The findings demonstrate the effectiveness of GBL in promoting safe driving behavior and enhancing ethical decision-making skills among learners. The study revealed an overall mean acceptance rate of 82%, indicating that the application was effective in creating awareness and educating users about driving ethics through GBL. The results also showed high levels of user satisfaction and engagement, with users describing the application as both useful and easy to use. Emphasizing enjoyable and ethically aware learning through GBL has the potential to significantly improve road safety and foster ethical driving behavior at a national level.

Keywords
Game-based learning, Driving ethics, Technology acceptance model (TAM), e-Driver application, User acceptance.

1.Introduction
In Malaysia, the high road mortality rate of 23.6 deaths per 100,000 people results in approximately 7,152 fatalities annually, making it a critical public health and safety concern [1]. A significant portion of these fatalities is attributed to noncompliance with established road safety protocols and a general lack of ethical driving behavior [2]. Providing young drivers with a strong foundation in driving ethics is essential for cultivating responsible road users and reducing accident risks. At the early stage of their driving experience, young drivers are particularly impressionable and still developing their judgment and decision-making skills.

Introducing ethical principles such as respect for traffic laws, consideration for other road users, and accountability for one's actions helps to instill a sense of responsibility and long-term safety awareness.

This highlights the urgent need for educational interventions that go beyond traditional methods and resonate more effectively with road users, particularly young or novice drivers. One promising approach is game-based learning (GBL), which has gained attention as an innovative pedagogical tool that integrates ethical lessons into engaging, interactive experiences [3]. By simulating real-world scenarios, GBL enables learners to develop practical decision-making skills [4] and better understand complex driving concepts through simplified, experiential learning models [5].

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GBL offers promise in road safety education due to its immersive nature, allowing learners to practice skills in a controlled and risk-free environment. This makes it an effective method for reinforcing concepts such as hazard perception, traffic sign recognition, and ethical decision-making. However, the implementation of GBL poses challenges, especially in aligning educational objectives with game mechanics. Without proper alignment, learners may focus more on game success than internalizing the intended moral and safety lessons. While GBL has shown clear benefits in raising awareness and improving knowledge of road safety, its effectiveness in producing long-term behavioral change remains inconsistent [6].

Several studies have shown that although participants of game-based programs demonstrate improved theoretical knowledge, this does not always translate into better real-world driving behavior [7–11]. This limitation emphasizes the need for more behaviorally focused game designs that not only convey information but also foster the motivation and self-regulation required for practical application. To address this, future GBL initiatives should incorporate principles from behavior change theories, provide timely feedback, and include personalized scenarios that reinforce ethical decision-making and safe driving habits. Additionally, continuous assessment and user feedback should be used to refine the learning experience and ensure it effectively shapes both attitudes and behaviors. In a nutshell, while GBL provides an innovative and engaging platform for road safety education, its true potential lies in thoughtfully designed interventions that go beyond awareness-building to actively promote ethical and safety-oriented behavior, particularly in high-risk environments such as Malaysia.

This paper is organized as follows: the literature review is presented in Section 2, the methodology in Section 3, the results in Section 4, the discussion in Section 5, and the conclusion in Section 6.

2.Literature review

GBL applications have emerged as powerful tools for enhancing awareness of driving ethics among novice drivers, ultimately promoting safer driving practices [12]. By creating engaging and interactive learning environments, GBL fosters responsibility and ethical awareness in drivers [13]. The design of these applications can be tailored to address specific learning outcomes related to driving ethics, making them effective pedagogical tools.

Chang and Yang [14] found that scaffolding in digital GBL enhances positive emotions, reduces cognitive load, and improves learning performance—particularly when adapted to different cognitive styles. However, their study was limited by its sample size and specific context. In a related study, Liu et al. [15] conducted an experimental investigation with novice drivers, revealing that GBL scenarios enhance critical thinking and ethical decision-making. While realistic scenarios improved learner engagement, the findings were limited to novice drivers. Similarly, personalized GBL scenarios tailored to different player types significantly enhanced both engagement and learning outcomes [16]. The customization improved the effectiveness of the application, although its applicability remained restricted to novice drivers.

Goodall [17] employed a mixed-methods approach combining surveys and interviews and concluded that ethical decision-making frameworks integrated into GBL significantly enhance safety education. Although the study was comprehensive, it was limited to a specific safety context. These findings collectively support the potential of GBL as an educational approach for instilling ethical awareness in driving behavior.

To enhance interactivity and appeal, GBL applications can be designed using the engagement, purpose, inspiration, challenge (EPIC) framework, which emphasizes engagement, purpose, inspiration, and challenge [18]:

- **Engagement** captures learners' attention through interactive gameplay, making ethical scenarios relatable and compelling.
- **Purpose** ensures that content aligns with real-world ethical dilemmas encountered by drivers, enhancing its relevance and applicability.
- **Inspiration** motivates learners by showcasing positive role models and illustrating the broader societal impact of ethical driving decisions.
- **Challenge** introduces complex decision-making situations that require critical thinking and moral reasoning, fostering deeper understanding.

By incorporating these elements, the EPIC framework provides a comprehensive and immersive learning experience that effectively promotes ethical awareness and responsible driving behavior.

For assessment purposes, the TAM offers a valuable framework for evaluating user acceptance of GBL applications. TAM focuses on three primary constructs: perceived usefulness (PU), perceived ease of use (PEOU), and perceived level of user satisfaction (PLUS), all of which significantly influence a user's intention to use (ITU) a given technology. In the context of GBL, these constructs offer important insights into how learners and educators perceive and engage with educational games. Sukirman et al. [19], for instance, employed TAM to assess an educational game for teaching computational thinking in a virtual reality environment. Their study demonstrated that PU, PEOU, attitude toward using, and ITU are critical in evaluating educational technologies. Similarly, Uiphanit et al. [20] used TAM to study GBL in teaching programming languages, finding that GBL fosters positive learning attitudes and enhances self-efficacy—aligning with TAM's assertion that PU plays a key role in driving user engagement. Bijl et al. [21] conducted a systematic review of serious games used for perception and performance assessment. They concluded that such games offer authentic learning environments and elicit relevant behaviors. Their findings highlight TAM's usefulness in understanding user acceptance, particularly the influence of PU and PEOU on users' attitudes and intentions to use serious games. However, they also noted research gaps in adaptivity and authenticity.

Key findings from the literature suggest that GBL applications are effective in enhancing driving ethics among novice drivers by fostering responsibility, critical thinking, and ethical awareness. Scaffolding techniques and realistic learning scenarios reduce cognitive load, improve positive emotions, and enhance learning outcomes—especially when adapted to individual cognitive styles. Ethical decision-making frameworks embedded in GBL further strengthen safety education. The EPIC framework contributes to an immersive, value-driven learning experience, while the TAM framework provides critical insights into user acceptance, PU, and usability. Together, these frameworks support the development and assessment of effective GBL applications for ethical driver education.

3.Methodology

The development of the GBL application, namely e-Driver, follows four key phases: user requirements, design, development, and prototype assessment. In the user requirements phase, educational needs are identified through curriculum references, literature reviews, and focus group discussions to understand learners' preferences and challenges. The design phase involves creating a game blueprint by integrating learning objectives with game mechanics, developing storyboards, and designing user interface prototypes in collaboration with road safety department officers. During the development phase, the prototype was built through iterative sprints, ensuring close collaboration between developers and driving trainers. This was followed by alpha testing to refine game mechanics and validate the educational content. Finally, in the prototype assessment phase, the TAM was employed to evaluate the application's usability and effectiveness, with user feedback collected to further enhance the application.

3.1Sampling

The study consisted of 10 female and 10 male participants, all of whom held a valid driving license and were in the process of adapting to real-world driving conditions. Purposive sampling was employed, with participants selected from among volunteers recruited through an advertisement targeting individuals who had obtained their driving license within the past two years.

This sampling strategy is justified based on Malaysia's licensing system, where individuals are eligible to apply for a car driving license at the age of 17. Upon passing the driving test, they are issued a probationary driving license (commonly referred to as the "P-license"), which remains valid for a period of two years. During this probationary period, drivers are required to adhere to stricter regulations, such as displaying a "P" plate on their vehicle and following specific road safety rules. After successfully completing the two-year probationary period without major traffic violations, they can apply for a full, unrestricted driving license. This group represents a critical demographic to study due to their inexperience and heightened vulnerability to road challenges. By selecting participants who are in the process of adapting to driving, the study ensures relevance to educational and behavioral interventions aimed at promoting safer driving habits. Literature indicates that sample sizes in preliminary studies often range from 10 to 30 participants, supporting the notion that a sample size of 20 can yield sufficient preliminary data [22].

Potential biases in the study design stem from the use of purposive sampling, which may introduce sampling bias, as the findings might not represent the experiences of young drivers outside the university context. Self-selection bias is another concern, as students who volunteered may possess stronger moral sensitivity or a greater interest in road safety, potentially skewing the results. Additionally, cultural and institutional factors unique to the university setting may limit the generalizability of the findings to other regions or populations. These biases may impact the study's outcomes, highlighting the need for future research to employ random sampling, a larger and more diverse participant pool, and mixed methods approaches to enhance the validity and reliability of the conclusions.

Participants with the same two-year probationary driving experience may not necessarily exhibit the same level of acceptance toward a driving-related intervention or technology, despite having similar driving backgrounds. Acceptance can vary due to several factors, including individual differences in learning styles, attitudes toward technology, personal experiences, and perceptions of road safety. Moreover, cultural, social, and psychological influences can significantly affect how participants perceive and engage with a driving safety application or intervention. Therefore, even within a seemingly homogeneous group, variations in acceptance and interaction with the learning module are to be expected.

3.2Instruments

In the assessment phase, a quantitative method was employed to gather user feedback using a 5-point Likert scale, with responses ranging from (1) strongly disagree to (5) strongly agree. The questionnaire measured four key constructs: PU, PEOU, PLUS, and ITU [23].

The TAM questionnaire, including the satisfaction component, was adapted from Linares et al. [23]. This established instrument is widely recognized in technology acceptance research for its reliability and robustness across various studies. Recent applications of TAM have demonstrated its effectiveness without the need for extensive pre-testing, further confirming its stability across different contexts. For instance, a study proposes a machine learning-based framework to predict public acceptance of shared autonomous vehicles, integrating elements of the TAM to analyze user attitudes and acceptance [24].

Additionally, the TAM questionnaire used in this study incorporates validated components from previous research, such as Linares et al. [23], retaining key constructs and original wording. Therefore, further piloting was deemed unnecessary. *Figure 1* illustrates the TAM framework, showing how its core constructs contribute to the ITU.

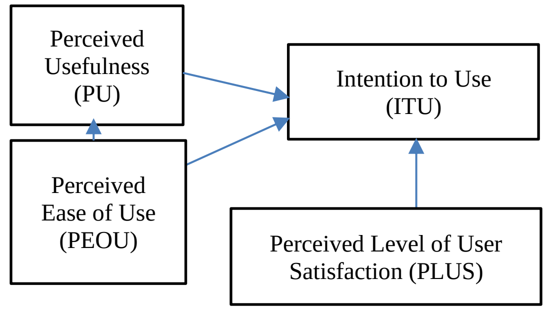

Figure 1 TAM with the satisfaction constructs (Adapted from Legramante et al. [25])

The questionnaire construction followed an iterative process, involving two experts with prior experience in TAM assessments and initial testing during the preliminary phase. Adjustments were made based on feedback, particularly to align the questions with the prototype module. Additionally, some items were reverse-scored to reduce response bias and encourage more thoughtful and accurate responses. The difference lies in the fact that PU evaluates the extent to which participants believe the technology enhances their task performance or fulfils its intended purpose, such as learning driving ethics. In contrast, PEOU assesses how easily participants can learn and use the prototype's features and applications. This study focuses on PU, PEOU, and PLUS—key factors influencing ITU in GBL applications. PU and PEOU are fundamental constructs of the TAM that drive technology adoption, as users are more likely to engage with a system they perceive as useful and easy to use. PLUS extends the model by assessing user satisfaction, which plays a crucial role in sustaining engagement and reinforcing ITU. The study prioritizes immediate user experience over long-term adoption trends, making PLUS a relevant addition for understanding user perceptions. By integrating PLUS, the study provides deeper insights into engagement and enjoyment, both of which indirectly contribute to ITU. Clearly linking PU, PEOU, and PLUS to TAM and ITU strengthens the study's framework and enhances its relevance in evaluating the effectiveness of GBL applications. The assessment was conducted over three days in parallel sessions, with a maximum of seven respondents per day. The session started with a briefing on the purpose of the assessment. The questionnaire was administered in person, using a face-to-face mode, following a structured process to ensure that participants were familiar with the prototype application. Before completing the questionnaire, participants engaged in a one-hour trial session, during which they explored the game with guidance from a facilitator who provided explanations and assistance. During the testing phase, participants played the game independently for approximately one hour without facilitation. After completing the game, they answered the questionnaire, which typically took 30 to 45 minutes. A key challenge in data collection was that some participants requested to replay the game again to better recall their experience and provide more accurate responses. To address this, participants were allowed to repeat the simulation as needed, ensuring the reliability of their responses. For data processing and analysis, the international business machines – statistical package for the social sciences (IBM SPSS) software was used, employing descriptive and frequency analysis techniques. Descriptive statistics, including the mean and standard deviation, were calculated for each item to determine the central tendency and variability of responses, providing insights into participant agreement levels. In this study, responses from the 5-point Likert scale were interpreted using predefined thresholds to ensure a structured analysis of participant feedback. Mean values from 1.00 to 1.80 indicate strong disagreement, reflecting a highly negative perception while scores from 1.81 to 2.60 denote disagreement, suggesting a negative response. A neutral stance is represented by mean values ranging from 2.61 to 3.40, indicating neither agreement nor disagreement. Positive perceptions are classified within the 3.41 to 4.20 range, signifying agreement, whereas mean scores between 4.21 and 5.00 represent strong agreement, reflecting a highly positive response. Based on these thresholds, responses with a mean score of 3.41 or higher are considered positive or agreeable, while those below 2.60 indicate negative perceptions. The neutral range (2.61–3.40) suggests a balanced or mixed viewpoint among respondents. This classification framework ensures clarity in interpreting user feedback and systematically evaluating participant attitudes and acceptance levels.

3.2.1Perceived usefulness (PU) dimension

PU refers to the user's perception of whether e-Driver can enhance their awareness of driving ethics. PU also influences other factors, such as ease of use. This is because users want to use simple tools that require minimal physical and mental effort to solve problems. User satisfaction is influenced by both PEOU and PU. This study assessed PU using four items. These items were specifically designed for this study. *Table 1* presents the responses to these four items.

3.2.2PEOU dimension

PEOU refers to the student's perception of e-Driver's ease of use, suggesting that increasing awareness of driving ethics requires minimal effort. Previous research has shown that participants are more likely to use a GBL application if they perceive it as requiring minimal effort. In this study, PEOU was assessed using four context-appropriate items, as presented in *Table 2.*

3.2.3Perceived level of user satisfaction (PLUS)

The PLUS is reflected in their evaluation and affective responses to the overall experience of an e-Driver's awareness of driving ethics. Four items in the PLUS are shown in *Table 3.*

Table 1 Items of perceived usefulness

Dimension	Operational Definitions	Measured Items
PU	*PU* reflects students' perceptions of whether using the e-Driver will enhance their awareness of driving ethics.	**PU1:** The game makes you more aware of driving ethics. **PU2:** The game makes you more aware of the importance of driving ethics. **PU3:** The game makes you reflect on every decision you make while driving. **PU4:** The game encourages you to become a more ethical driver.

Table 2 Items of perceived ease of use

Dimension	Operational Definitions	Measured Items
PEOU	*PEOU* refers to the students' perception that using an e-Driver to raise their awareness of driving ethics will require effort.	**PEOU1:** You are able to control the car and navigate easily. **PEOU2:** It is easy for me to understand the game objectives. **PEOU3:** The user interface (UI) is simple and easy

		to operate. **PEOU4:** I think this application is easy to use.

Table 3 Items of perceived level of user satisfaction

Dimension	Operational Definitions	Measured Items
PLUS	PLUS refers to the student's perception of how using the e-Driver will impact their overall experience and awareness of driving ethics.	**PLUS1:** You had fun using e-Driver. **PLUS1:** You find the gameplay included in e-Driver to be interesting. **PLUS3:** In the future, if there were similar learning application or software were to be created, I would use it. **PLUS4:** Overall, you find e-Driver application interesting and satisfying.

4.Results

The followings are the results of the TAM.

4.1Perceived usefulness (PU) dimension

For PU1, all respondents either agreed (50%) or strongly agreed (50%), resulting in a high mean score of 4.500. PU2 had a slightly lower mean score of 3.900, with 20% of respondents moderately agreeing, 40% agreeing, and 30% strongly agreeing. PU3 showed a pattern similar to PU2, with a mean score of 3.850, indicating moderate agreement. PU4 had a higher mean score of 4.250, with a mix of moderate agreement (10%), agreement (55%), and strong agreement (35%). Overall, the average mean score across all items is approximately 4.125, suggesting that respondents generally found the items useful. This highlights the varying degrees of PU among the items, with PU1 being the most positively received. This indicates that the participants find that e-Driver is useful in creating awareness of driving ethics and delivering related ethical instructions for driving. The results for the four items PU1, PU2, PU3, PU4 are as follows (*Table 4*).

Table 4 Perceived usefulness dimension evaluation

Item	SD	D	MA	A	SA	Mean
PU1	0	0	0	10	10	4.500
PU2	0	2	4	8	6	3.900
PU3	0	3	6	2	9	3.850
PU4	0	0	2	11	7	4.250
Average Mean						4.125

SD= Strongly Disagree, D= Disagree, MA= Moderately, A=Agree, and SA=Strongly Agree

4.2PEOU dimension

PEOU1 has the highest mean score of 4.500, indicating that most respondents found this aspect of the item very easy to use, with a significant number agreeing (25%) or strongly agreeing (20%). PEOU2 follows with a mean score of 4.200, showing positive feedback with no strong disagreements and most responses at the agree (60%) or strongly agree (30%) level. PEOU3 has a mean score of 4.250, reflecting a high level of consensus among respondents, with no disagreements and most responses in moderate agreement (5%), agreement (65%), and strong agreement (30%). PEOU4 has the lowest mean score of 3.900 but still indicates overall agreement, with a few disagreements (10%) and moderate agreements (15%), yet most responses lean towards agreement (50%) and strong agreement (25%). The average mean score across all items is 3.913, suggesting that, overall, participants found the items relatively easy to use. This suggests that the user respondents generally agree that the e-Driver application is easy to use, the content is understandable, and the related ethical driving instructions are adequately provided. However, there is a noticeable difference in one of the items regarding the ease of controlling the car, and some of the users find it difficult to drive and control the car in the application. *Table 5* presents the results for the PEOU dimension. This dimension was evaluated using four specific items (PEOU1 to PEOU4), which yielded an average mean score.

Table 5 Perceived ease of use dimension evaluation

Item	SD	D	MA	A	SA	Mean
PEOU1	1	5	5	5	4	4.500
PEOU2	0	0	2	12	6	4.200
PEOU3	0	0	1	13	6	4.250
PEOU4	0	2	3	10	5	3.900
Average Mean						3.913

SD= Strongly, D = Disagree, MA= Moderately Agree, A = Agree, and SA=Strongly Agree

4.3Perceived level of user satisfaction dimension

Table 6 presents the evaluation of the PLUS dimension, based on four items (PLUS1 to PLUS4).

For PLUS1, most respondents strongly agreed (55%), agreed (35%), moderately agreed (5%), and disagreed (5%), resulting in a high mean score of 4.400. PLUS2 also reflected high satisfaction, with 45% of respondents agreeing, 45% strongly agreeing, and 5% moderately agreeing, yielding a mean score of 4.300.

PLUS3 showed a slightly lower mean score of 4.150, with 45% strongly agreeing, 35% agreeing, 10% moderately agreeing, and 10% disagreeing. PLUS4 closely mirrored the results of PLUS1, with 40% strongly agreeing, 50% agreeing, and 5% moderately agreeing, leading to a mean score of 4.400.

Overall, the average mean score across all four items was approximately 4.275, indicating a generally high level of user satisfaction. These results highlight that the majority of users were satisfied with the application, with a significant proportion expressing strong agreement across the evaluated items. This positive feedback suggests that the application effectively supports the development of ethical driving awareness.

Table 6 Perceived level of user satisfaction dimension evaluation

Item	SD	D	MA	A	SA	Mean
PLUS1	0	1	1	7	11	4.400
PLUS2	0	1	1	9	9	4.300
PLUS3	0	2	2	7	9	4.150
PLUS4	0	1	1	10	8	4.400
Average Mean						4.275

SD= Strongly, D = Disagree, MA= Moderately Agree, A = Agree, and SA=Strongly Agree

4.4Overall TAM assessment

Based on *Figure 2*, the results of the study indicate that the GBL prototype was generally well received by users. The PU score of 4.125 suggests that users found the tool valuable in enhancing their understanding of driving ethics. The PEOU score was 3.9125, indicating a positive response, though slightly lower than PU. The PLUS recorded the highest score at 4.275, reflecting strong user satisfaction.

As shown in *Table 7*, the overall mean score across all three dimensions was 4.1, corresponding to an overall acceptance rate of 82%. These findings confirm the effectiveness and acceptability of the GBL prototype in promoting ethical driving awareness among users.

Table 7 Overall TAM

Dimension	Item Code	Total Mean	%
PU	PU	4.125	83%
Perceived of Ease Use	PEU	3.913	78%
PLUS	PLUS	4.275	86%
Overall Mean		**4.100**	
Percentage Mean			**82%**

5.Discussion

The study calculated an overall mean acceptance rate of 82%, derived from the average of the mean values across each dimension. The highest scores for PU1 and PEU1 indicate that users found the prototype application highly useful (PU1) and easy to navigate (PEU1). The challenges integrated into the gameplay effectively helped users understand driving ethics and their benefits, reinforcing the functional value (PU) of the application. Additionally, the straightforward user interface (UI) and structured instructional design made the application more accessible, leading to a strong PEU1. The engaging nature of the game and its ability to simplify complex ethical scenarios contributed to the high satisfaction (PLUS) score of 4.275, highlighting the interactive and motivating aspects of the learning experience.

In contrast, PEU4 received a lower rating, indicating challenges in controlling the car within the game. This suggests that while the application is generally easy to use, its driving mechanics may require refinements. Users may have struggled with steering precision, responsiveness, or sensitivity of the controls, which impacted their experience. Prior research has shown that usability issues in GBL applications often arise from overly complex control schemes or a lack of adaptive difficulty settings. Addressing these concerns by improving control sensitivity, providing adjustable settings, or incorporating a tutorial mode could enhance the overall ease of use and drive higher engagement.

The variations in PU, PEOU, and PLUS scores provide actionable insights for refining the application. Improving game mechanics and making more control intuitiveness would enhance PEOU, ensuring a smoother user experience. Additionally, maintaining engaging instructional methods while improving gameplay fluidity can further strengthen PU and PLUS, ultimately reinforcing 82% of users' ITU and long-term engagement with the application.

Based on these findings, the following recommendations can be made:

a. Refinement of User Interface: Improve the user interface, graphics, and game navigation to enhance ease of use. This may include simplifying instructions, offering clearer guidance, and optimizing the design for different user preferences.

b. Continuous Engagement: Maintain and build upon high satisfaction levels by regularly updating game content, introducing new scenarios, and incorporating user feedback.
c. Further Testing: Conduct additional testing with a larger and more diverse group to ensure the tool's effectiveness across different demographics, leading to a more universal application of the GBL tool.

5.1Evaluating the results in relation to the TAM theoretical framework

The results of this study support the theoretical framework provided by the TAM. TAM posits that PU and PEOU are critical determinants of user acceptance and ITU technology. The findings indicate strong overall acceptance of the application, with a percentage mean of 82%. This suggests that users generally perceive the application positively. The PU score of 4.125 confirms that users found the GBL tool beneficial for learning driving ethics and safety awareness, aligning with TAM's assumption that PU influences technology acceptance. The high PU score supports the theoretical framework, indicating that users are more likely to adopt technology that they perceive as valuable in enhancing their learning experience. The 3.913, while still positive, is slightly lower than PU and PLUS. This suggests that although users found the application relatively easy to navigate, some usability challenges may exist. According to TAM, ease of use should reduce effort and encourage adoption, and the near-agreeable PEU score partially supports this assumption. The slightly lower score compared to PU suggests that improving the system's usability could enhance acceptance even further. The PLUS score of 4.275 is the highest among the three dimensions, indicating that users were highly satisfied with the GBL experience. This reinforces TAM's extended model, which suggests that satisfaction is a critical factor in engagement and sustained use. The strong satisfaction rating supports the framework, showing that positive user experiences drive technology acceptance, especially in interactive learning environments. The results largely support TAM, as high PU, PEOU, and PLUS scores correlate with strong user acceptance. However, the slightly lower PEOU score suggests that ease of use alone is not the sole determinant of acceptance. Future research should examine additional behavioral factors—such as motivation, gamification elements, and long-term engagement—to further refine TAM's applicability in GBL for road safety education.

5.2Benchmarking with previous research

The comparison between the current study and Liu et al.'s study [26] on TAM in mixed reality GBL reveals a similar trend in user perception. Both studies report a high PU, with Liu et al. [26] scoring 0.89 and the current study 0.83, indicating that users find the GBL approach beneficial in improving their understanding. This consistency suggests that gamified learning applications, regardless of the technology used, are effective in engaging users and enhancing their learning experiences. The results reinforce the idea that game-based education tools, whether mixed reality or conventional digital formats, can be valuable in driving knowledge acquisition. Despite the high PU, both studies show a lower PEOU compared to PU, with Liu et al. [26] at 0.86 and the current study at 0.78. This pattern indicates that while users recognize the benefits of the application, they also encounter usability challenges. The slightly lower PEOU in the current study may be attributed to interface complexity, system navigation, or the need for additional guidance in using the game effectively. However, this does not significantly reduce user engagement, as users are still willing to use the system if they perceive it as valuable. The ITU remains high in both studies (Liu et al. [26]: 0.89, Current Study: 0.82), reinforcing the idea that users are willing to adopt the tool despite usability challenges. This aligns with TAM research findings that high PU can compensate for lower PEOU in determining ITU. The results suggest that improving ease of use could further enhance user adoption, but as long as the tool provides substantial learning benefits, users will continue engaging with it. Overall, this comparison highlights the effectiveness of GBL in education and the importance of balancing usability and instructional value.

5.3Study limitations

While the GBL prototype was generally well-received, several limitations should be acknowledged. First, the study's sample—comprising university students in Malaysia—may limit the generalizability of the findings to other geographic regions or cultural driving contexts. Secondly, the application currently includes a limited number of content levels, which may restrict users from experiencing a broader range of driving scenarios and ethical challenges. Expanding the game with diverse scenarios could enhance instructional effectiveness by allowing users to navigate various real-world driving conditions, reinforcing their understanding of ethical decision-making. Third, the experimental setup required users to interact with the prototype for a limited time, which may not fully capture the long-term learning impact of the application. Extending testing periods or adding multiple sessions would allow users to explore the features more comprehensively, leading to more accurate assessments of usability and effectiveness. Addressing these limitations in future iterations could further improve the application's engagement, instructional depth, and overall impact on driving ethics education.

A complete list of abbreviations is listed in *Appendix I.*

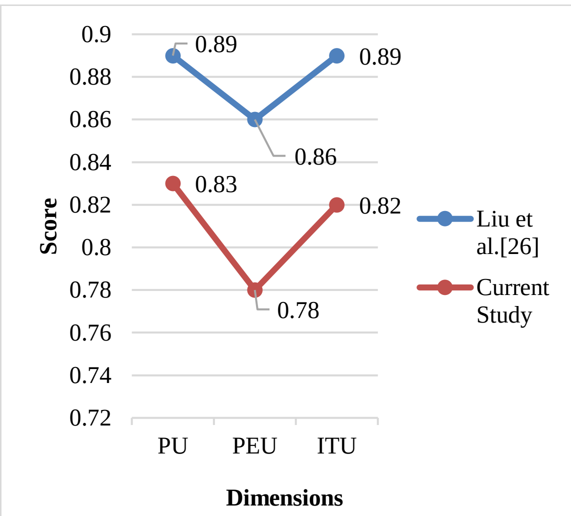

Figure 2 Benchmarking with previous research using TAM

6.Conclusion and future work

This study examined the use of GBL to raise awareness of driving ethics among young drivers in Malaysia. TAM was employed to evaluate students' acceptance of the e-Driver application, focusing on key dimensions such as PU, PEOU, and PLUS. The study found that PU, PEOU, and PLUS are significantly linked and crucial factors in determining user acceptance and ITU the application. The application was effective in creating awareness and educating users about driving ethics through engaging gameplay. High levels of user satisfaction and interest were observed, with users describing the application as useful, easy to use, and enjoyable. However, some users found controlling the car challenging, indicating areas for improvement in the interface and mechanics. Future work should focus on refining the user interface and game mechanics to enhance ease of use, making the application more intuitive and user-friendly. This includes simplifying instructions, offering clearer guidance, and optimizing the design for different user preferences. Additionally, expanding the study to include a larger and more diverse sample of participants and exploring the long-term impact of the application on driving behavior and ethical decision-making will provide deeper insights. Continuous engagement through regular updates and incorporating user feedback will further enhance the tool's effectiveness, ultimately contributing to improved road safety and ethical driving practices.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Data availability

The data used in this study were collected at Universiti Teknologi MARA (UiTM), Jasin Campus, Malaysia, and involved students who were in the early stages of driving after obtaining their licenses. While the data are not publicly available, they may be provided by the corresponding author upon reasonable request.

Author’s contribution statement

Siti Salwa Salleh: Study conception, experimental design, original draft writing, interpretation of results and manuscript review and editing. **Muhammad Syafiq Saharudin:** Prototype design and development, and experiment execution. **Ismassabah Ismail:** Supervision, development of assessment protocols and instrumentation, and analysis and interpretation of results.

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Appendix I

S. No.	Abbreviation	Description
1	EPIC	Engagement, Purpose, Inspiration, Challenge
2	GBL	Game-Based Learning
3	IBM SPSS	International Business Machines – Statistical Package for the Social Sciences
4	ITU	Intention to Use
5	PEOU	Perceived Ease of Use
6	PLUS	Perceived Level of User Satisfaction
7	PU	Perceived Usefulness
8	TAM	Technology Acceptance Model
9	UiTM	Universiti Teknologi MARA