

Student Perceptions and Implementation Framework for Augmented Reality in Forensic Chemistry and Toxicology Education

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Abstract: Augmented reality (AR) enhances visualization, engagement, and learning within technology-enhanced education. Nevertheless, its application in forensic chemistry and toxicology remains insufficiently explored, particularly concerning students' readiness and perceptions. This study investigated students' knowledge, perceptions, and challenges related to AR integration in forensic chemistry and toxicology, and developed an implementation framework. A quantitative design was employed, involving 457 Bachelor of Science in Criminology students who completed the course during the Academic Year 2025–2026. Data collection was conducted using a 42-item, expert-validated instrument, which demonstrated excellent internal consistency with a Cronbach's alpha of 0.942. Descriptive statistics, including weighted means and standard deviations, were utilized to analyze the responses. The findings revealed moderate knowledge of AR, while perceptions of learning engagement, motivation, usefulness, and ease of use were high. Significant perceived challenges included technological costs, internet connectivity, device accessibility, training requirements, and institutional support. The results indicate favorable perceptions, alongside a need to enhance technological familiarity and implementation readiness. Consequently, an AR readiness profile and a five-phase framework—comprising preparation, capacity building, implementation, monitoring and evaluation, and sustainability—were proposed. The study emphasizes the importance of orientation, training, infrastructure, and institutional support. Future research should assess the framework's effectiveness in improving learning outcomes and practical competencies in forensic science education.

Keywords: *Augmented Reality, Forensic Chemistry and Toxicology, Technology Acceptance, Student Perceptions, Educational Technology*

INTRODUCTION

Digital technologies are changing the way we learn, making education more interactive and focused on the learner. Augmented reality (AR) is a major part of this shift, mixing virtual elements with the real world to boost how we visualize, engage with, and remember information. Studies show that AR has a positive effect in fields such as science, medicine, engineering, and health education. For instance, when AR is combined with cooperative project-based learning, it can improve academic performance, motivation, problem-solving skills, and teamwork, especially in artificial intelligence education (Adi et al., 2025). Using AR in gamified learning also increases student engagement, confidence, and satisfaction in science classes (Ateş & Polat, 2025). Although there are hurdles such as cost and technical readiness, AR is seen as a gamechanger that equips students for tech-driven careers and supports hands-on, inclusive learning worldwide (Garg et al., 2025; Khlaif et al., 2025).

Forensic education involves a solid grasp of complex scientific ideas, lab work, and crime scene investigation techniques. This is especially true for areas such as forensic chemistry and toxicology, which deal with abstract processes that are not easy to visualize using traditional teaching methods. Augmented reality (AR) can be helpful in these situations. It offers interactive simulations, 3D models, and immersive experiences that help make these concepts clearer and connect theory and practice in forensic training (Golomingi et al., 2023). Despite all technological advancements, many colleges and universities still use traditional lecture methods for forensic

courses. In addition, students have different levels of comfort and experience with using AR as a learning tool. It is important to understand their views because they are the ones who benefit the most from these innovations. By examining students' expectations, the benefits they see, their concerns, and their willingness to use AR, we can develop effective ways to integrate it into the classroom. Research on AR acceptance shows that students are generally ready to embrace it, but there are concerns about its practicality and benefits. This highlights the need for awareness and training to encourage the positive adoption of AR in forensic education (Arifitama, 2024; Volioti et al., 2022). Addressing these issues can boost engagement and improve learning outcomes in forensic science programs.

Although extensive research has examined the application of augmented reality (AR) in science, engineering, and medical education, its application in forensic chemistry and toxicology remains unexplored. Most studies focus on learning outcomes and technology effectiveness, with limited attention to students' knowledge, perceptions, and readiness for AR integration prior to implementation. There is a notable lack of evidence regarding forensic students' attitudes toward AR and the challenges they foresee in adopting it academically. Additionally, few studies have investigated student perspectives to develop AR integration frameworks tailored to forensic education. Addressing these gaps will support effective AR-based instructional design in forensic science courses.

RESEARCH QUESTIONS

This study aims to examine students' views on the integration of augmented reality (AR) in forensic chemistry and toxicology. Specifically, it seeks to answer the following questions

1. What is the level of students' knowledge regarding augmented reality technology in forensic chemistry and toxicology education?
2. What are the students' perceptions of the integration of augmented reality in forensic chemistry and toxicology in terms of perceived usefulness, perceived ease of use, learning engagement, and learning motivation?
3. What challenges do students perceive in the integration of augmented reality in forensic chemistry and toxicology instruction
4. Based on the findings of the study, what augmented reality integration framework may be proposed to enhance learning in forensic chemistry and toxicology?

Theoretical and Conceptual Mapping of the study

Figure 1 shows how this study is set up to look at the use of augmented reality (AR) in teaching forensic chemistry and toxicology. This study is based on the technology acceptance model (TAM), which basically says that whether students accept AR depends on how useful they think it is and how easy they find it to use. These perceptions influence their attitudes and intentions to use AR, which eventually leads to its adoption in forensic education. The framework also highlights that students' knowledge of AR is the starting point, while their views on its usefulness, ease of use, learning engagement, and motivation are explored. It also takes into account the challenges of integrating AR, which might impact how ready and willing students are to embrace the technology. From the findings, a proposed AR integration framework is developed to help implement it effectively and improve learning experiences in forensic chemistry and toxicology.

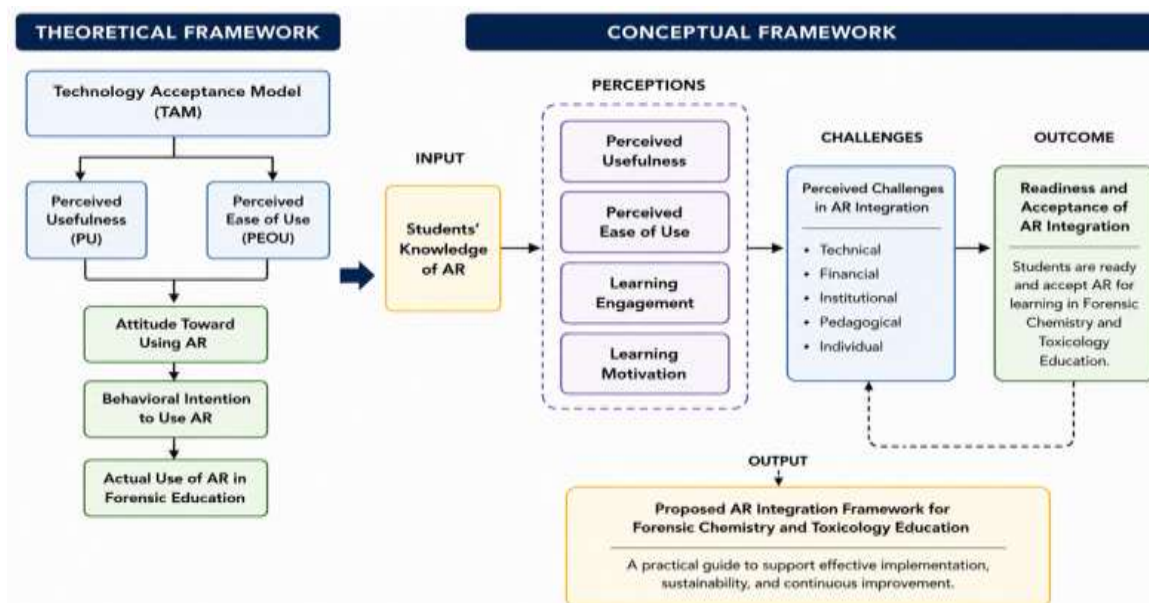


Figure 1 Theoretical and Conceptual Mapping of the study

METHODS

Research Design

This study embarked on a descriptive quantitative journey to explore the landscape of students' knowledge, perceptions, learning engagement, learning motivation, and perceived hurdles in weaving augmented reality (AR) into the fabric of Forensic Chemistry and Toxicology instruction. This approach was fitting, as it aimed to systematically capture and measure the respondents' existing perceptions and experiences without altering variables or introducing experimental interventions. The study delved into six dimensions: knowledge of augmented reality, perceived usefulness, perceived ease of use, learning engagement, learning motivation, and perceived challenges in AR integration. The quantitative findings laid the groundwork for crafting a proposed AR Integration Framework, designed to steer the potential incorporation of augmented reality into the realm of forensic science education.

Research Locale

This study was conducted at a private higher education institution offering a Bachelor of Science in Criminology program. The institution was chosen because it provides courses in forensic chemistry and toxicology, which offer students valuable academic exposure to forensic science concepts and laboratory-related learning activities. This setting was deemed suitable for examining students' perceptions of the potential application of augmented reality in forensic science instruction, particularly in supporting the visualization of complex concepts and the development of interactive learning experiences.

Research Participants and Sampling Technique

The study engaged 457 Bachelor of Science in Criminology students, all of whom were either currently enrolled in or had completed the Forensic Chemistry and Toxicology course during the academic year 2025–2026. These students were ideal participants because their academic background provided a solid foundation for evaluating the potential applications of augmented reality in forensic science education. Stratified random sampling was employed to ensure representation from various class sections. The population was divided into strata based on class sections, and respondents were randomly selected from these groups. This method was designed to ensure comprehensive representation across the sections and minimize selection bias. Ultimately, the sample comprised 457 respondents, whose responses were thoroughly analyzed and interpreted within the context of the participating students and the study's institutional framework.

Research Instrument

Data were collected using a structured questionnaire adapted from Anselmo et al. (2025), entitled *The Potential of Portable AR in Physics Education: A Study of Student Perceptions*. The instrument was thoughtfully modified to reflect the context of forensic chemistry and toxicology instruction and the specific objectives of the present study. It consisted of 42 items divided into six dimensions: knowledge of augmented reality, perceived usefulness, perceived ease of use, learning engagement, learning motivation, and perceived challenges in AR integration, with seven indicators for each dimension. Each item was measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The questionnaire was designed to obtain quantitative information regarding students' familiarity with AR, their perceptions of its instructional value and usability, its perceived influence on engagement and motivation, and the challenges associated with its potential implementation. The wording and contextual references of the items were carefully modified to make them relevant to forensic science education while retaining the six dimensions identified in the study to ensure consistency between the research objectives, data collection, and statistical analysis.

Validity and Reliability of the Instrument

To establish the content relevance and appropriateness of the adapted questionnaire, the instrument underwent expert validation by specialists in educational technology, forensic science, and research methodology. The validation process focused on the relevance, clarity, and suitability of the questionnaire items in relation to the objectives and context of the study. The instrument was revised based on the experts' recommendations before its administration to the actual respondents. A pilot test was conducted with 30 Bachelor of Science in Criminology students who were not included in the actual sample. The pilot test data were analyzed using Cronbach's alpha to determine the internal consistency of the six dimensions of the questionnaire. The reliability coefficients ranged from 0.852 to 0.924 across the six constructs, while the overall instrument obtained a Cronbach's alpha coefficient of 0.942. These results indicated satisfactory to excellent internal consistency among the questionnaire items and supported the use of the instrument for the main data collection. The reliability analysis was interpreted separately from evidence of content validity, as internal consistency alone does not establish the overall validity of a research instrument.

Data Gathering Procedure

Prior to data collection, the researchers secured the necessary approval from the appropriate institutional authorities. Following approval, the respondents were informed of the purpose of the study, the nature of their participation, and the procedures involved in completing the questionnaire. Informed consent was obtained before participation. The validated questionnaire was administered electronically through Google Forms to facilitate the distribution, retrieval, and organization of responses. Participation was voluntary, and respondents were informed of their right to decline participation or withdraw from the study without penalty. After the survey administration, the completed questionnaires were reviewed for completeness and consistency. The responses were subsequently encoded, organized, and prepared for statistical analysis. The resulting dataset was used to describe the students' knowledge, perceptions, engagement, motivation, and perceived challenges regarding the potential integration of augmented reality in forensic chemistry and toxicology instruction.

Statistical Treatment of Data

The data collected from the respondents were analyzed using descriptive statistical techniques appropriate to the study objectives. Frequency counts and percentages were used to summarize respondents' demographic characteristics and provide a descriptive profile of the participating students. The weighted mean and standard deviation were computed to determine the level and distribution of responses for each of the six dimensions: knowledge of augmented reality, perceived usefulness, perceived ease of use, learning engagement, learning motivation, and perceived challenges in AR integration. The weighted mean was used to summarize the respondents' ratings for each indicator and construct, while the standard deviation described the variability of their responses. The

resulting descriptive statistics were interpreted using the established verbal interpretation scale. The findings were synthesized to identify areas of perceived readiness, instructional potential, and implementation challenges associated with AR integration. These results served as the empirical basis for developing the proposed AR Integration Framework, which was intended to provide guidance for the potential integration of augmented reality into Forensic Chemistry and Toxicology instruction.

RESULTS AND DISCUSSION

Table 1 Reliability Analysis of the Research Instrument Based on the Pilot Test

Construct	Number of Items	(α)	Interpretation
Knowledge of Augmented Reality	7	0.852	Good Reliability
Perceived Usefulness	7	0.917	Excellent Reliability
Perceived Ease of Use	7	0.901	Excellent Reliability
Learning Engagement	7	0.924	Excellent Reliability
Learning Motivation	7	0.913	Excellent Reliability
Perceived Challenges in AR Integration	7	0.884	Good Reliability
Overall Instrument	42	0.942	Excellent Reliability

Table 1 shows how reliable the research tool is for checking students' knowledge, perceptions, learning engagement, motivation, and the challenges they feel when using augmented reality (AR) in forensic chemistry and toxicology classes. The results are pretty solid, with all six areas showing good to excellent internal consistency. The Cronbach's alpha coefficients are between 0.852 and 0.924. Learning engagement scored the highest reliability, while knowledge of AR was the lowest, but both are still within acceptable limits. Overall, the tool got a Cronbach's alpha of 0.942, which means it's really consistent. This backs up using the questionnaire for gathering actual data from the study participants.

Figure 2. Radar Chart of the Overall Mean Scores of Students' Views on the Integration of Augmented Reality in Forensic Chemistry and Toxicology Education

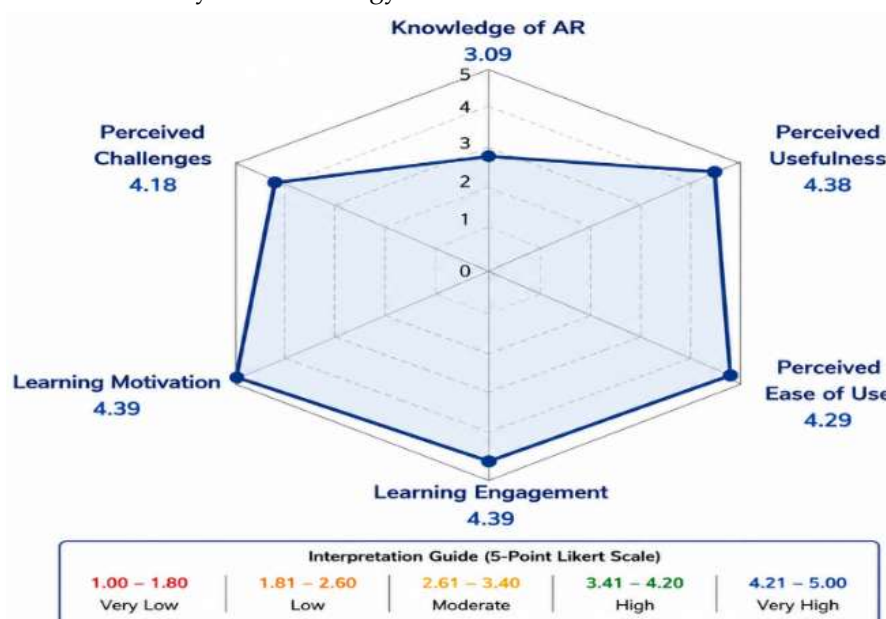


Figure 2 shows the average scores from 457 BS Criminology students on how augmented reality (AR) is being used in forensic chemistry and toxicology classes. Students felt most engaged and motivated, scoring an average of 4.39, closely followed by how useful they found AR (4.38) and how easy it was to use (4.29). These scores are all considered very high. However, when it came to challenges, the score was a bit lower at 4.18, and their knowledge of AR was the lowest at 3.09, which is moderate. This tells us that while students generally have a positive view of AR, they could benefit from more knowledge and hands-on experience with it. These results back up Davis's (1989) findings on the importance of

perceived usefulness and ease of use for accepting new technology. Ateş and Polat (2025) also pointed out how AR can boost student engagement and motivation. Therefore, to make AR work well in forensic education, it is crucial to have orientation sessions, hands-on training, good internet access, and support from the institution.

Figure 3. Overall Mean Scores of Students' Perceptions of Augmented Reality Integration in Forensic Chemistry and Toxicology Education

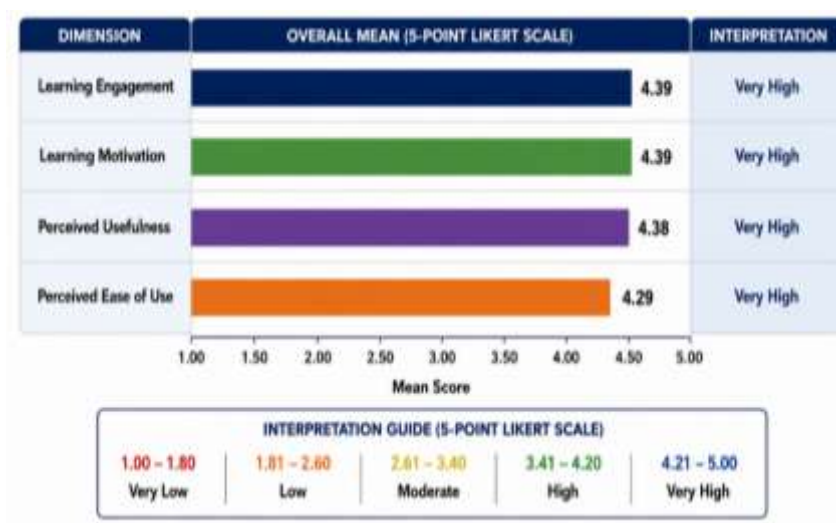


Figure 3 shows that students are highly engaged and motivated when it comes to learning, with both scoring the highest average ($M = 4.39$). Right behind are perceived usefulness ($M = 4.38$) and perceived ease of use ($M = 4.29$), all considered very high. This indicates that students believe that augmented reality (AR) can make forensic chemistry and toxicology lessons more interactive, motivating, and useful. This supports the findings of Alaulamie and Alshwiah (2021) regarding AR acceptance and motivation, and what Ateş and Polat (2025) said about the perks of AR and gamification in science education. Golomingi et al. (2023) also discussed AR's potential in forensic science and medicine. Overall, these findings suggest that AR can enhance engaging and meaningful learning experiences in forensic education.

Figure 4. Priority Matrix of Students' Readiness for Augmented Reality Integration in Forensic Chemistry and Toxicology Education

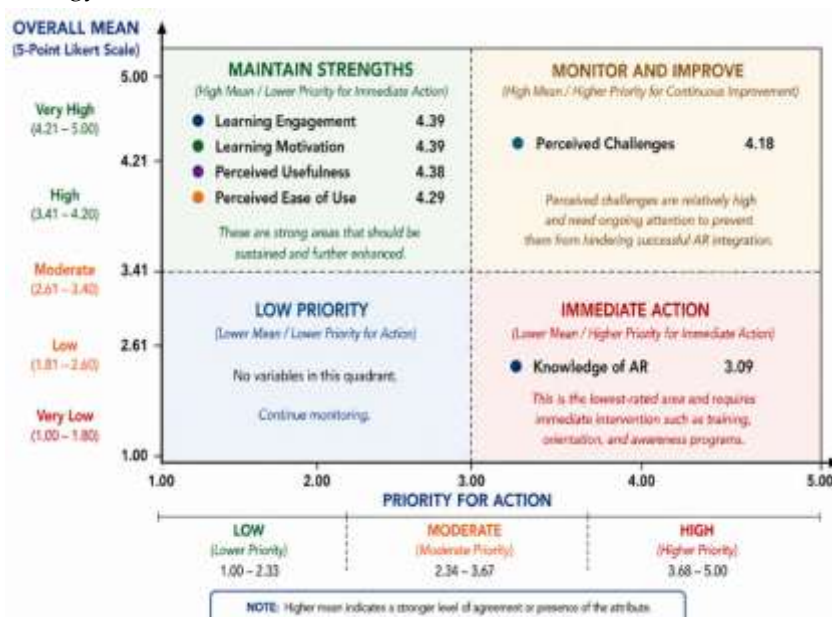


Figure 4 shows the key areas for integrating AR based on the findings of the study. We found that

perceived usefulness ($M = 4.38$), perceived ease of use ($M = 4.29$), learning engagement ($M = 4.39$), and learning motivation ($M = 4.39$) all fell under the "Maintain Strengths" category. On the other hand, perceived challenges ($M = 4.18$) are in the "Monitor and Improve" section, and knowledge of AR ($M = 3.09$) needs "Immediate Action." This tells us that while students generally have a positive view, there is a need to boost their knowledge and hands-on experience with AR. Arifitama (2024) pointed out how important technology readiness is for AR acceptance, and Indarta et al. (2025) highlighted the need for training, tech resources, and tackling implementation challenges in AR-based education. Therefore, to make AR work well in forensic education, we need orientation programs, hands-on training, good Internet access, and support from institutions.

Figure 5. Augmented Reality Readiness Profile for Forensic Chemistry and Toxicology Education



Figure 5 presents the proposed Augmented Reality (AR) Readiness Profile for Forensic Chemistry and Toxicology Education, which summarizes students' readiness and priority areas for AR integration into the curriculum. The findings show that perceived usefulness ($M = 4.38$), perceived ease of use ($M = 4.29$), learning engagement ($M = 4.39$), and learning motivation ($M = 4.39$) represent the major strengths of AR integration in education. These results indicate that students recognize the potential of AR to make forensic learning more interactive, accessible, and motivating. This is supported by Sakr and Abdullah (2024), whose systematic review found that AR and virtual reality can enhance learners' motivation, attention, understanding, and knowledge retention across different educational settings. However, students' moderate knowledge of AR ($M = 3.09$) suggests the need to improve their familiarity with and practical exposure to the technology. Kuncoro et al. (2024) emphasized that successful AR integration requires interactive learning experiences, appropriate instructional design, and collaboration between educators and technology developers. Therefore, the readiness profile highlights the importance of maintaining students' positive perceptions by providing AR orientation, hands-on activities, and sufficient institutional support. These strategies may help bridge the gap between students' favorable attitudes and their actual readiness to use AR in forensic chemistry and toxicology courses.

Figure 6: Implementation Framework Based on the findings of this study, an augmented reality integration framework may be proposed to enhance learning in forensic chemistry and toxicology.

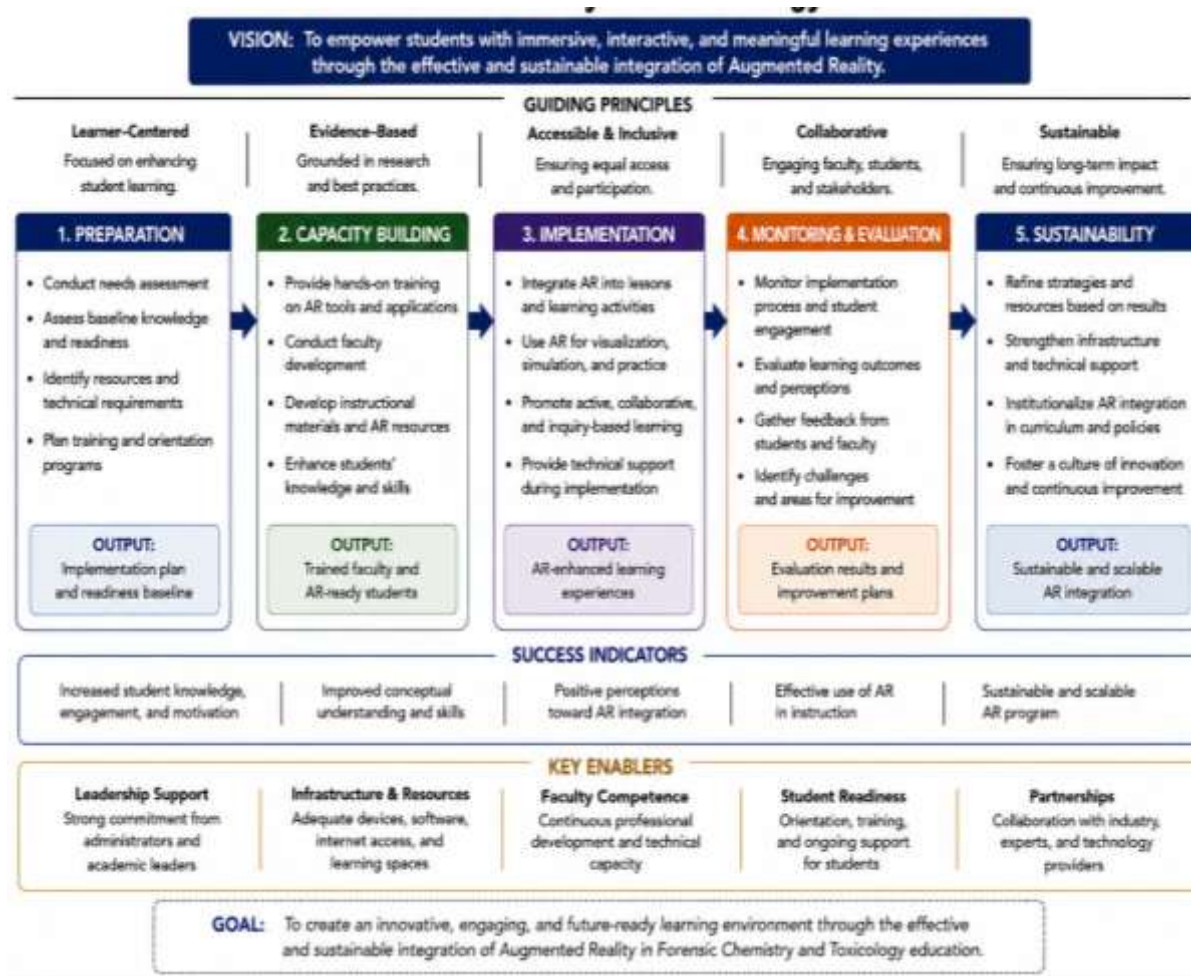


Figure 6 presents the proposed implementation framework for AR integration in forensic chemistry and toxicology education. The framework consists of five phases: preparation, capacity building, implementation, monitoring and evaluation, and sustainability. The preparation phase involves assessing students' readiness, identifying available resources, and establishing implementation objectives. Capacity building focuses on developing faculty and student competencies through training and the preparation of AR-based instructional materials. The implementation phase integrates AR into classroom instruction and laboratory activities, while monitoring and evaluation assess student engagement, learning outcomes, and implementation challenges. Finally, the sustainability phase emphasizes continuous improvement, curriculum integration, and institutional support. These phases are consistent with Wang and Li (2024), whose systematic review emphasized the importance of theory-driven training design and the purposeful use of extended reality technologies in teacher education. Similarly, Mena et al. (2023) highlighted the role of professional training in developing educators' capacity to use AR in educational settings. Therefore, the framework demonstrates that effective AR integration requires more than the availability of digital technology. It also requires prepared educators, appropriate instructional materials, adequate infrastructure, and continuous evaluation. By following these phases, educational institutions may establish a structured and sustainable approach to integrating AR into forensic chemistry and toxicology education.

CONCLUSION

This study examined the perceptions, knowledge, and perceived challenges of Bachelor of Science in Criminology students regarding the integration of augmented reality (AR) in forensic chemistry and toxicology instruction. The findings revealed that students had moderate knowledge of AR, indicating the need to strengthen their familiarity and practical exposure to technology. Nevertheless, respondents

expressed very high perceptions of its usefulness, ease of use, learning engagement, and learning motivation, suggesting that they recognize its potential to support more interactive, engaging, and learner-centred forensic education. Despite these favorable perceptions, students identified challenges related to technological costs, internet connectivity, access to compatible devices, training, and institutional support. In response to these findings, the proposed AR Readiness Profile and Implementation Framework provides a structured guide for preparing students and instructors, developing technological and instructional resources, integrating AR into classroom and laboratory activities, and monitoring its implementation. Overall, the study highlights the importance of combining students' positive perceptions with adequate preparation, accessible technology, and institutional support to facilitate the potential integration of AR into forensic science education. However, since the study focused on self-reported perceptions and did not involve an actual AR intervention, the proposed framework requires further implementation and evaluation to determine its applicability and effectiveness in improving students' learning outcomes.

RECOMMENDATIONS

In light of the study's findings and conclusions, it is recommended that educational institutions offering courses in forensic chemistry and toxicology establish structured orientation programs, workshops, and practical training sessions. These initiatives aim to enhance students' understanding and familiarity with augmented reality (AR) technology prior to its comprehensive integration into the curriculum. Faculty members should be encouraged to integrate AR-based learning activities, virtual simulations, and interactive lab exercises into their teaching methods to boost student engagement, motivation, and comprehension of intricate forensic concepts. Institutional leaders should allocate resources to develop the necessary technological infrastructure, such as reliable internet access, compatible mobile devices, software, and technical support, to reduce implementation challenges and ensure that all students have equal access to AR-enhanced learning. Additionally, ongoing professional development opportunities should be offered to instructors to improve their skills in designing and delivering AR-supported lessons. Academic institutions are also advised to utilize the proposed AR Readiness Profile and Implementation Framework as guides for planning, executing, monitoring, and maintaining AR initiatives in forensic education. Finally, future researchers should assess the effectiveness of the proposed framework through experimental or quasi-experimental studies, examine the long-term effects of AR on students' academic performance and practical skills, and investigate its use in other forensic science courses and higher education fields to further substantiate the benefits of AR integration in teaching and learning.

LIMITATIONS OF THE STUDY

This study was limited to 457 BS Criminology students at Private College of the Philippines in NCR during Academic Year 2025–2026. It focused on students' perceptions, knowledge, engagement, motivation, and challenges regarding the potential integration of augmented reality in forensic chemistry and toxicology instruction. Since the study used a descriptive quantitative design and self-reported questionnaires, the findings reflect students' opinions and do not establish the actual effects of AR on academic performance or learning outcomes. Furthermore, the proposed AR integration framework was developed based on the findings but was not yet implemented or evaluated. Future studies may involve other institutions and assess the framework through actual classroom and laboratory applications.

FUTURE RESEARCH DIRECTIONS

Future researchers may conduct similar studies in other higher education institutions to determine whether the findings are consistent across different academic settings and student populations. Further studies may also employ experimental or quasi-experimental research designs to evaluate the actual effects of augmented reality on students' academic performance, knowledge retention, engagement, and practical skills in forensic chemistry and toxicology. The proposed AR integration framework may be implemented and evaluated through classroom and laboratory activities to determine its

applicability, effectiveness, and areas for improvement. Future research may also explore the perspectives of instructors and laboratory personnel regarding the integration of AR into forensic science education, particularly in terms of technological readiness, accessibility, and implementation challenges. These directions may provide additional evidence to support the development of effective and sustainable AR-based instructional approaches in criminology education.

ETHICS STATEMENT

This study observed ethical principles throughout the research process. Before data collection, permission was obtained from the appropriate authorities. The respondents were informed about the purpose of the study, and their participation was voluntary. Informed consent was obtained, and participants were assured that their responses would be treated with confidentiality and used solely for academic and research purposes. No respondent was required to participate, and they were free to withdraw from the study at any time without penalty. The researchers ensured that the collected data were securely handled, analyzed, and reported accurately without revealing the identities of the participants. The study upheld the principles of respect, privacy, confidentiality, and integrity in conducting and reporting the research.

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AI DISCLOSURE STATEMENT

During the preparation of this manuscript, the authors used Grammarly and ChatGPT as supplementary tools for language refinement, grammar editing, clarity, and organization. These tools served only as writing aids and did not replace the authors' scholarly judgment or responsibilities. All AI-assisted content was carefully reviewed, verified, and revised by the authors of this study. The authors take full responsibility for the accuracy, integrity, originality, and content of the final published article.