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RESEARCH PAPER

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Enhancing competency-based learning in automotive servicing NC II through augmented reality: Implications for occupational health, ergonomics, and environmental safety

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ABSTRACT

Augmented Reality (AR) has emerged as a promising instructional technology for strengthening competency-based learning in technical-vocational education by integrating technical skills with occupational health, ergonomics, and environmental safety. However, empirical evidence on its application in Automotive Servicing NC II, particularly within the Philippine context, remains limited. This study evaluated the effectiveness of AR-supported instruction in improving automotive servicing competency, occupational health and safety practices, ergonomic practices, and environmental safety among Automotive Servicing NC II students. A mixed-method quasi-experimental pretest-posttest control-group design was employed involving 30 students from Cebu Technological University–Moalboal Campus, with 15 students assigned to an AR-supported experimental group and 15 to a conventional instruction control group. Quantitative data were collected using validated competency, occupational health and safety, ergonomic, and environmental safety assessment checklists, while qualitative data were obtained through semi-structured interviews with eight students from the experimental group. Descriptive and inferential statistics and thematic analysis were used to analyze the data. The AR-supported group demonstrated greater improvements in automotive competency (16.27 vs. 6.80 points), occupational health and safety (9.74 vs. 4.67 points), ergonomic practices (7.93 vs. 3.80 points), and environmental safety (12.87 vs. 6.27 points) than the control group. Significant differences between groups were observed for automotive competency ($p < .001$), occupational health and safety ($p = .002$), ergonomic practices ($p = .006$), and environmental safety ($p = .003$). Interview findings further revealed improved procedural understanding, hazard recognition, ergonomic awareness, environmental responsibility, and learner engagement. The findings demonstrate that AR-supported instruction is an effective supplementary approach for enhancing competency-based learning while fostering safer, more ergonomic, and environmentally responsible workplace practices in Automotive Servicing NC II.

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INTRODUCTION

The rapid advancement of Augmented Reality (AR) has created new opportunities to enhance competency-based learning in technical-vocational education by providing interactive, contextualized, and learner-centered instructional experiences. By integrating digital information with real-world environments, AR enables learners to visualize complex procedures and receive real-time guidance during practical tasks, thereby improving engagement, procedural understanding, and learning outcomes (Sakr and Abdullah, 2024; Mohammadhossein *et al.*, 2024).

In Automotive Servicing NC II, competency extends beyond technical proficiency to include occupational health and safety, ergonomic work practices, and environmental responsibility. Automotive servicing exposes learners to mechanical, chemical, and ergonomic hazards that require proper use of personal protective equipment, safe body mechanics, hazard recognition, and responsible handling of automotive wastes. Consequently, competency-based education should prepare learners not only to perform servicing procedures accurately but also to protect their health and minimize environmental risks (World Health Organization [WHO], 2026; Occupational Safety and Health Administration [OSHA], 2026).

AR offers a promising approach for integrating these competencies within authentic workshop environments. Previous studies have shown that immersive technologies improve procedural learning and technical performance in automotive education while supporting occupational safety training (Win *et al.*, 2022; Lan *et al.*, 2024; Hülagü and Erkarslan, 2021). However, most existing studies have focused primarily on technical competency or learner engagement, with limited attention to the simultaneous development of occupational health and safety, ergonomic practices, and environmental safety within competency-based automotive education. Moreover, empirical evidence on AR-supported Automotive Servicing NC II instruction in the Philippine technical-vocational context remains limited.

In the Philippines, the Technical Education and Skills Development Authority (TESDA) promotes competency-based training that integrates technical skills with safe work practices, while the Department of Labor and Employment (DOLE, 2018) emphasizes compliance with occupational safety and health standards. These priorities underscore the need for instructional approaches that strengthen technical competence alongside workplace safety and environmental responsibility.

To address these gaps, this study examined the effectiveness of AR-supported instruction in enhancing competency-based learning among Automotive Servicing NC II students. Specifically, it evaluated the effects of AR on automotive competency, occupational health and safety, ergonomic practices, and environmental safety, while exploring students' learning experiences with the technology. By integrating technical competency with biosciences, occupational health, ergonomics, and environmental stewardship, the study contributes to the development of a more human-centered approach to competency-based technical-vocational education.

METIRIAL AND METHODS

Research design

This study employed a mixed-methods quasi-experimental pretest–posttest control-group design to evaluate the effectiveness of Augmented Reality (AR)-supported instruction in enhancing competency-based learning among Automotive Servicing NC II students. The quantitative component compared the learning outcomes of students who received AR-supported instruction with those who underwent conventional competency-based instruction. The qualitative component complemented the quantitative findings by exploring students' experiences, perceived benefits, and challenges associated with the use of AR during practical automotive servicing activities. This mixed-methods approach provided both measurable evidence of learning outcomes and a deeper understanding of how AR influenced students' competency development, occupational health awareness, ergonomic practices, and environmental responsibility.

Research setting and participants

The study was conducted at the College of Technology, Cebu Technological University–Moalboal Campus, Philippines. Thirty (30) Automotive Servicing NC II students participated in the study. Using an intact-group assignment consistent with a quasi-experimental design, 15 students were assigned to the experimental group, which received AR-supported instruction, while the remaining 15 students formed the control group and received conventional competency-based instruction. Equal group sizes facilitated meaningful comparisons between the two instructional approaches.

Participants were selected based on the following criteria: (1) enrollment in the Automotive Servicing NC II program during the conduct of the study; (2) willingness to participate voluntarily; and (3) completion of all phases of the research, including the pretest, instructional intervention, and posttest. Eight students from the experimental group were purposively selected for individual interviews to provide detailed accounts of their learning experiences with AR.

Research intervention

The instructional intervention consisted of an AR-enhanced learning program developed to support the competencies required in Automotive Servicing NC II while simultaneously reinforcing occupational health, ergonomic awareness, and environmental safety practices. The AR application presented interactive three-dimensional visualizations and contextual overlays that guided learners through servicing procedures using step-by-step instructions. Throughout each activity, students received real-time prompts related to component identification, tool selection and handling, workplace hazards, personal protective equipment (PPE), proper body positioning, safe lifting techniques, prevention of musculoskeletal strain, handling of automotive fluids, spill prevention, waste segregation, and environmentally responsible disposal practices.

Students in the control group completed the same learning competencies, workshop activities, instructional time, and performance requirements using conventional competency-based instruction consisting of classroom discussions, instructor demonstrations, printed learning materials, and supervised hands-on workshop exercises. Maintaining identical competencies and instructional duration for both groups allowed differences in learning outcomes to be attributed primarily to the instructional approach.

Research instruments

Data were collected using four structured performance assessment instruments and one qualitative interview guide. Technical competency was evaluated using a Competency Performance Checklist consisting of 20 performance indicators aligned with the competencies prescribed in the TESDA Automotive Servicing NC II Training Regulations. Occupational health and safety practices were assessed through a 15-item Occupational Health and Safety Checklist, which measured hazard recognition, PPE compliance, safe tool handling, and adherence to workshop safety procedures. Ergonomic practices were evaluated using a 10-item Ergonomic Practice Checklist that examined body positioning, working posture, lifting techniques, and behaviors associated with the prevention of musculoskeletal strain. Environmental responsibility was measured using a 10-item Environmental Safety Checklist, which assessed proper handling of automotive fluids, spill prevention, waste segregation, storage, and disposal practices.

To complement the quantitative findings, a semi-structured interview guide containing eight open-ended questions was administered to selected students from the experimental group. The interview explored learners' perceptions of AR, its usefulness in understanding automotive procedures, its contribution to workplace safety and ergonomic awareness, and the challenges encountered during implementation.

Before data collection, all research instruments and instructional materials underwent expert review by specialists in automotive technology, technical-vocational education, occupational safety and health, ergonomics, and educational technology to establish content validity, clarity, and relevance. Revisions were incorporated based on their recommendations prior to implementation.

Data-gathering procedure

After obtaining institutional approval, the researcher secured informed consent from all participants and oriented them regarding the objectives, procedures, and ethical safeguards of the study. Baseline data were first collected through pretest assessments measuring automotive competency, occupational health and safety practices, ergonomic practices, and environmental safety behaviors.

The experimental group then participated in the AR-supported instructional program, whereas the control group received conventional competency-based instruction covering the same learning competencies within the same instructional period. Following completion of the intervention, both groups completed the posttest using the same assessment instruments and evaluation criteria applied during the pretest.

Subsequently, eight students from the experimental group participated in individual semi-structured interviews to describe their experiences with the AR learning environment. All quantitative data were checked for completeness before statistical analysis, while interview recordings were transcribed verbatim and prepared for qualitative analysis.

Ethical considerations

The study adhered to established ethical principles governing educational research. Institutional permission was obtained before conducting the investigation, and informed consent was secured from all participants. Students were informed of the purpose of the study, the procedures involved, potential benefits and minimal risks, and their right to decline participation or withdraw at any stage without academic penalty.

Confidentiality and privacy were maintained by assigning identification codes instead of participant names. Electronic records, interview transcripts, and assessment data were securely stored and used exclusively for research purposes. During workshop activities, participants were required to comply with standard occupational safety procedures, including the appropriate use of personal protective equipment, to ensure a safe learning environment.

Data analysis

Quantitative data were analyzed using both descriptive and inferential statistics. Frequency and percentage were used to summarize participant characteristics, while means and standard deviations described competency performance, occupational health and safety practices, ergonomic practices, and environmental safety behaviors before and after the intervention. Changes within each instructional group were examined using paired-samples *t*-tests, whereas differences between the experimental and control groups were analyzed using independent-samples *t*-tests. Where appropriate, analysis of covariance (ANCOVA) was employed to control for baseline differences between groups. Effect sizes were also calculated to determine the practical significance of the intervention. Statistical significance was evaluated at the 0.05 level.

Qualitative interview data were analyzed using thematic analysis. Interview transcripts were read repeatedly, coded systematically, and grouped into categories based on recurring ideas and patterns. Themes were subsequently developed to describe students' perceptions of AR, including its influence on procedural understanding, workplace safety, ergonomic awareness, environmental responsibility, learning engagement, and implementation challenges.

Finally, the quantitative and qualitative findings were integrated during interpretation to provide a comprehensive evaluation of the effectiveness of AR-supported instruction in improving competency-based learning and promoting occupational health, ergonomics, and environmental safety among Automotive Servicing NC II students.

RESULTS AND DISCUSSION

Automotive servicing competency performance

Table 1 presents the pretest and posttest competency performance of the experimental and control groups. At baseline, both groups demonstrated comparable competency levels, with mean pretest scores of 72.40 (SD= 5.18) and 71.87 (SD= 5.36), respectively, indicating similar initial competencies before the intervention.

Following the intervention, both groups improved; however, the experimental group demonstrated a substantially greater increase in competency performance. The mean score of students who received AR-supported instruction increased from 72.40 to 88.67 (gain = 16.27), whereas the control group improved from 71.87 to 78.67 (gain = 6.80). These findings suggest that integrating AR into competency-based instruction enhanced students' practical performance beyond that achieved through conventional teaching.

Table 1. Pretest and posttest competency performance of the experimental and control groups

Group	Test	Mean	SD	Interpretation
Experimental (AR)	Pretest	72.40	5.18	Moderate
Experimental (AR)	Posttest	88.67	4.21	Very High
Control	Pretest	71.87	5.36	Moderate
Control	Posttest	78.67	5.02	High

Legend: 90.00–100.00 = Very High; 80.00–89.99 = High; 70.00–79.99 = Moderate; 60.00–69.99 = Low; below 60.00 = Very Low; SD = Standard Deviation.

The greater improvement may be attributed to AR's ability to provide real-time visual guidance, interactive procedural support, and contextual information during workshop activities. By integrating digital instructions with hands-on practice, AR enables learners to better understand component identification, procedural sequencing, and correct task execution, thereby facilitating the transfer of theoretical knowledge into practical skills. This explanation is consistent with the cognitive theory of multimedia learning, which emphasizes that meaningful integration of visual and verbal information enhances learning while reducing unnecessary cognitive load (Mayer, 2021).

The present findings are consistent with previous studies on immersive learning technologies in automotive education. Win *et al.* (2022) reported that AR- and VR-based instruction improved students' understanding of automobile engine assembly by providing clearer procedural guidance than conventional instructional approaches. Similarly, Lan *et al.* (2024) demonstrated that virtual reality-based automotive training enhanced students' learning effectiveness and operational efficiency through interactive simulations and guided practice. Although the present study employed AR rather than fully immersive VR, both technologies support visualization and procedural learning that are essential for competency development in technical-vocational education.

Occupational health and safety practices

Table 2 presents the occupational health and safety (OHS) performance of the experimental and control groups before and after the intervention. At baseline, both groups demonstrated comparable OHS practices, with mean pretest scores of 28.53 (SD = 3.12) for the experimental group and 28.80 (SD = 3.05) for the control group, indicating similar levels of safety awareness prior to the implementation of AR-supported instruction.

Table 2. Occupational health and safety performance before and after the intervention

Group	Test	Mean	SD	Interpretation
Experimental (AR)	Pretest	28.53	3.12	Moderate
Experimental (AR)	Posttest	38.27	2.41	Very High
Control	Pretest	28.80	3.05	Moderate
Control	Posttest	33.47	2.86	High

Legend: 36.00–40.00 = Very High; 31.00–35.99 = High; 26.00–30.99 = Moderate; 21.00–25.99 = Low; 20.00 and below = Very Low; SD = Standard Deviation.

Following the intervention, OHS performance improved in both groups; however, the improvement was more pronounced among students who received AR-supported instruction. The experimental group's mean score increased from 28.53 to 38.27 (gain = 9.74), while the control group improved from 28.80 to 33.47 (gain = 4.67). These findings suggest that AR-supported learning was more effective in strengthening students' occupational health and safety practices than conventional competency-based instruction.

The greater improvement may be attributed to the integration of contextual safety prompts within the AR learning environment. During workshop activities, students received real-time reminders on hazard recognition, proper use of personal protective equipment (PPE), safe tool handling, and accident prevention, allowing safety principles to be reinforced at the point of task performance. Embedding safety guidance into authentic learning activities is known to promote better retention and application of safe work practices than instruction delivered separately from practical tasks (Hülagü and Erkarslan, 2021).

The findings are consistent with Hülagü and Erkarslan (2021), who reported that AR-based occupational health and safety training increased students' awareness of workplace hazards and reduced unsafe behaviors by providing immediate visual warnings during vocational training. The results also support the broader concept of occupational health promoted by the World Health Organization (2026), which emphasizes hazard prevention and the creation of safe working environments as essential components of worker health and well-being.

Ergonomic practices

Table 3 presents the ergonomic practice performance of the experimental and control groups before and after the intervention. At baseline, both groups exhibited comparable ergonomic practices, with mean pretest scores of 28.80 (SD = 2.94) for the experimental group and 28.67 (SD = 3.01) for the control group, indicating similar levels of ergonomic awareness prior to the intervention.

After the instructional period, ergonomic practices improved in both groups; however, the improvement was substantially greater among students who received AR-supported instruction. The experimental group's mean score increased from 28.80 to 36.73 (gain = 7.93), whereas the control group improved from 28.67 to 32.47 (gain = 3.80). These findings suggest that AR-supported instruction was more effective than conventional teaching in promoting ergonomically appropriate work practices during automotive servicing activities.

The greater improvement may be attributed to the AR application's ability to provide real-time visual cues on correct body positioning, working posture, lifting techniques, and safe movement while students performed practical tasks. By embedding ergonomic guidance directly into workshop activities, AR enabled learners to immediately apply proper body mechanics, thereby reinforcing safe work habits and reducing practices that may contribute to musculoskeletal strain. This interpretation is consistent with the Occupational Safety and Health Administration (OSHA, 2026), which identifies awkward postures, repetitive movements, and improper lifting as major risk factors for work-related musculoskeletal disorders, and emphasizes the importance of ergonomic interventions in preventing these injuries.

Table 3. Ergonomic practice performance before and after the intervention

Group	Test	Mean	SD	Interpretation
Experimental (AR)	Pretest	28.80	2.94	Moderate
Experimental (AR)	Posttest	36.73	2.35	Very High
Control	Pretest	28.67	3.01	Moderate
Control	Posttest	32.47	2.72	High

Legend: 36.00–40.00 = Very High; 31.00–35.99 = High; 26.00–30.99 = Moderate; 21.00–25.99 = Low; 20.00 and below = Very Low; SD = Standard Deviation.

Table 4. Environmental safety performance before and after the intervention

Group	Test	Mean	SD	Interpretation
Experimental (AR)	Pretest	71.33	6.14	High
Experimental (AR)	Posttest	84.20	4.87	Very High
Control	Pretest	70.93	5.92	High
Control	Posttest	77.20	5.36	High

Legend: 90.00–100.00 = Very High; 80.00–89.99 = High; 70.00–79.99 = Moderate; 60.00–69.99 = Low; below 60.00 = Very Low; SD = Standard Deviation.

The findings also support the World Health Organization (2003), which recognizes ergonomics as a key strategy for preventing musculoskeletal disorders through appropriate workplace design and safe work practices. In the context of automotive servicing, integrating ergonomic instruction with practical training enables students to develop technical competence while adopting healthier and safer working behaviors.

Environmental safety practices

Table 4 presents the environmental safety performance of the experimental and control groups before and after the intervention. At baseline, both groups demonstrated comparable levels of environmental safety practices, with mean pretest scores of 71.33 (SD = 6.14) for the experimental group and 70.93 (SD = 5.92) for the control group, indicating similar awareness of environmentally responsible automotive servicing practices prior to the intervention.

Following the intervention, environmental safety performance improved in both groups; however, the experimental group showed a substantially greater improvement. The mean score of the AR-supported group increased from 71.33 to 84.20 (gain = 12.87), whereas the control group improved from 70.93 to 77.20 (gain = 6.27). These findings suggest that AR-supported instruction was more effective than conventional instruction in promoting environmentally responsible practices during automotive servicing.

The greater improvement may be attributed to the integration of contextual environmental prompts within the AR learning environment. During practical activities, students received real-time guidance on the proper handling of automotive fluids, spill prevention, waste segregation, storage, and appropriate disposal of hazardous materials. Presenting environmental safety information within authentic servicing tasks likely enabled students to better understand the environmental consequences of their actions and immediately apply appropriate practices. This contextualized approach is consistent with recent evidence indicating that AR enhances learning by providing interactive and situated instructional experiences that facilitate the application of knowledge in real-world settings (Anuar *et al.*, 2025; Mohammadhossein *et al.*, 2024).

From an occupational and environmental health perspective, proper management of used oil, coolants, batteries, solvents, and other automotive wastes is essential for minimizing risks to both human health and the environment. Integrating these practices into competency-based instruction therefore promotes not only technical proficiency but also environmental responsibility among future automotive technicians.

Table 5. Summary of pretest and posttest performance

Outcome variable	Experimental pretest	Experimental posttest	Gain	Control pretest	Control posttest	Gain
Automotive competency	72.40	88.67	16.27	71.87	78.67	6.80
Occupational health & safety	28.53	38.27	9.74	28.80	33.47	4.67
Ergonomic practices	28.80	36.73	7.93	28.67	32.47	3.80
Environmental safety	71.33	84.20	12.87	70.93	77.20	6.27

Legend: 90.00–100.00 = Very High; 80.00–89.99 = High; 70.00–79.99 = Moderate; 60.00–69.99 = Low; below 60.00 = Very Low; SD = Standard Deviation.

Table 6. Statistical comparison of experimental and control groups

Outcome variable	Mean Gain–AR	Mean Gain–Control	Mean difference	p-value	Decision
Automotive competency	16.27	6.80	9.47	< .001	Significant
Occupational health & safety	9.74	4.67	5.07	.002	Significant
Ergonomic practices	7.93	3.80	4.13	.006	Significant
Environmental safety	12.87	6.27	6.60	.003	Significant

Comparison of learning outcomes

Tables 5 and 6 summarize the overall learning outcomes of the experimental and control groups across the four measured domains: automotive competency, occupational health and safety, ergonomic practices, and environmental safety. Although both groups demonstrated improvements following instruction, the experimental group consistently achieved greater gains in all outcome variables, indicating the added value of AR-supported instruction in competency-based automotive education.

The largest improvement in the experimental group was observed in automotive competency (gain = 16.27), followed by environmental safety (12.87), occupational health and safety (9.74), and ergonomic practices (7.93). In comparison, the control group recorded smaller gains of 6.80, 6.27, 4.67, and 3.80, respectively (Table 5). These findings suggest that AR-supported instruction enhanced not only students' technical skills but also their awareness and application of safe, ergonomic, and environmentally responsible workplace practices.

The statistical analysis further supports these observations (Table 6). Significant differences were found between the experimental and control groups across all four outcome variables, with automotive competency ($p < .001$), occupational health and safety ($p = .002$), ergonomic practices ($p = .006$), and environmental safety ($p = .003$). Collectively, these results indicate that the improvements observed in the experimental group were unlikely to have occurred by chance and were associated with the AR-supported instructional approach.

The consistent gains across multiple learning domains may be explained by the ability of AR to integrate procedural guidance, safety reminders, ergonomic cues, and environmental prompts into authentic workshop activities. Rather than treating technical skills and workplace safety as separate learning components, AR presents them simultaneously within the context of task performance, allowing students to apply knowledge immediately while completing automotive servicing procedures. This contextual and interactive learning environment is recognized as one of the principal educational advantages of AR, contributing to improved engagement, knowledge application, and practical skill development (Mohammadhossein *et al*., 2024; Anuar *et al*., 2025).

Students' experiences with AR-supported learning

Table 7 presents the qualitative findings from interviews with eight students who participated in the AR-supported instructional program. Overall, the participants described AR as a valuable learning tool that enhanced their understanding of automotive servicing procedures while promoting occupational health and safety, ergonomic awareness, and environmental responsibility. The qualitative findings complement the quantitative results by providing insights into how AR influenced students' learning experiences during practical workshop activities.

A prominent theme was improved procedural understanding, with students reporting that the step-by-step visual guidance made servicing procedures easier to follow and reduced uncertainty during task execution. This finding suggests that AR facilitated procedural learning by allowing students to visualize each stage of the servicing process while performing the actual task, consistent with previous studies showing that AR enhances comprehension of complex technical procedures through contextualized visual support (Mohammadhossein *et al.*, 2024; Lan *et al.*, 2024).

Table 7. Emerging themes from students' experiences with AR (8 students selected)

Theme	Key student experiences	Selected verbatim statement
Improved procedural understanding	AR made servicing procedures easier to visualize and follow.	"The AR guide helped me follow the steps correctly, especially when I was not sure what to do next."
Enhanced safety awareness	Visual warnings reinforced PPE use and hazard recognition.	"The safety reminders made me more aware of the hazards and reminded me to use PPE."
Improved ergonomic awareness	Students became more conscious of posture and physical strain.	"I learned to position my body properly so I would not easily get tired or hurt."
Environmental responsibility	AR strengthened awareness of fluid handling, spills, segregation, and disposal.	"The AR reminders helped me remember how to handle used oil and dispose of automotive waste properly."
Increased engagement	Interactive visual guidance made practical activities more interesting.	"Using AR made the activity more interesting because I could see the instructions while doing the actual task."
Technology-related challenges	Students experienced adjustment difficulties and needed technical guidance.	"At first, it was difficult to use the AR device, so I needed guidance from the instructor."

Students also highlighted enhanced safety awareness, noting that the embedded visual reminders reinforced the use of personal protective equipment (PPE), hazard recognition, and safe tool handling. These experiences support the quantitative improvement observed in occupational health and safety practices and align with the findings of Hülagü and Erkarslan (2021), who reported that AR-based safety training increased learners' awareness of workplace hazards by providing immediate visual guidance during vocational activities.

Another recurring theme was improved ergonomic awareness. Participants reported becoming more conscious of proper body positioning and working posture while performing automotive servicing tasks. Similarly, students expressed greater environmental responsibility, indicating that AR reminders strengthened their understanding of proper handling of automotive fluids, waste segregation, spill prevention, and disposal practices. These responses suggest that integrating ergonomic and environmental guidance into practical instruction can promote safer and more sustainable workplace behaviors.

Students further described AR as making practical activities more interactive and engaging, increasing their motivation to participate in workshop exercises. However, some participants acknowledged initial difficulties in operating the AR system and emphasized the importance of instructor guidance during the early stages of implementation. This finding indicates that while AR has considerable educational potential, its successful integration depends on adequate orientation, technical support, and effective instructional facilitation (Anuar *et al.*, 2025).

Quantitative and qualitative data integration

Table 8 presents the integration of the quantitative and qualitative findings, demonstrating a high degree of convergence between the two datasets.

Quantitatively, students who received AR-supported instruction achieved significantly greater improvements in automotive competency, occupational health and safety, ergonomic practices, and environmental safety than those who received conventional instruction. Qualitatively, these improvements were reflected in students' experiences, as participants consistently reported better procedural understanding, increased safety awareness, improved ergonomic practices, greater environmental responsibility, and higher learning engagement during workshop activities.

Table 8. Integration of quantitative and qualitative findings

Research outcome	Quantitative finding	Qualitative finding	Integrated interpretation	Implication
Automotive Competency	AR group gained 16.27 points, compared with 6.80 in the control group; $p < .001$.	Students reported improved visualization and understanding of step-by-step procedures.	AR-supported instruction enhanced procedural understanding and practical competency.	AR can strengthen competency-based automotive skills training.
Occupational Health and Safety	AR group gained 9.74 points, compared with 4.67; $p = .002$.	Students reported greater awareness of hazards, PPE, and safe tool handling.	Visual safety prompts reinforced occupational health and safety behaviors during actual tasks.	AR can support safer automotive workshop practices and injury prevention.
Ergonomic Practices	AR group gained 7.93 points, compared with 3.80; $p = .006$.	Students became more conscious of posture, body positioning, and physical strain.	AR helped translate ergonomic concepts into observable and actionable workplace behaviors.	AR can promote musculoskeletal health and ergonomic awareness.
Environmental Safety	AR group gained 12.87 points, compared with 6.27; $p = .003$.	Students reported increased awareness of fluid handling, spill prevention, waste segregation, and disposal.	Contextual AR reminders strengthened environmentally responsible servicing practices.	AR can integrate environmental protection into automotive skills education.
Learning Engagement	Higher posttest performance was observed in the AR group across all outcomes.	Students described AR activities as more interesting and interactive.	Increased engagement may have supported active participation and practical learning.	AR can make competency-based learning more interactive and learner-centered.
Technology Challenges	Despite positive gains, AR required additional instructional support.	Students reported adjustment difficulties, device-handling issues, and the need for instructor guidance.	AR effectiveness depends on adequate orientation, technical support, and instructor supervision.	Institutions should provide training, technical resources, and teacher support when implementing AR.

The convergence of these findings suggests that the effectiveness of AR extends beyond improving technical performance alone. Students attributed their improved competency to the availability of real-time visual guidance and step-by-step procedural support, while embedded safety prompts and contextual reminders enhanced their awareness of workplace hazards, proper body positioning, and environmentally responsible practices. These experiences provide plausible explanations for the higher posttest scores observed across all four outcome variables. Similar observations have been reported in previous studies, which indicate that AR promotes contextualized learning by integrating instructional content directly into authentic task environments, thereby improving both learning outcomes and learner engagement (Mohammadhossein *et al.*, 2024; Anuar *et al.*, 2025).

The integrated findings also highlight the value of AR as a holistic instructional approach in competency-based technical-vocational education. Rather than teaching technical skills, occupational safety, ergonomics, and environmental responsibility as separate concepts, AR enabled these learning domains to be experienced simultaneously during actual automotive servicing activities. This integrated learning environment supports the development of technically competent, safety-conscious, and environmentally responsible future automotive technicians while reinforcing meaningful connections between theory and practice.

IMPLICATIONS

Biosciences, occupational health, and environmental health

The findings highlight the interdisciplinary value of integrating AR into Automotive Servicing NC II by linking technical competency with biosciences, occupational health, ergonomics, and environmental safety. Beyond improving procedural skills, AR reinforced safe work practices, proper body mechanics, hazard recognition, and environmentally responsible behaviors during authentic workshop activities. This contextualized approach enables students to apply health, safety, and environmental principles while performing actual servicing tasks, promoting the development of technically competent, safety-conscious, and environmentally responsible automotive technicians. Although the findings are promising, they should be interpreted cautiously due to the study's limited sample size. Future research involving larger samples, multiple institutions, and longer intervention periods is recommended to validate and extend these findings.

Teaching

The findings suggest that AR can serve as an effective supplementary instructional tool in Automotive Servicing NC II by making practical learning more interactive, contextualized, and learner-centered. Integrating AR into workshop instruction allows teachers to simultaneously reinforce technical procedures, occupational safety, ergonomic practices, and environmental responsibility while maintaining essential instructor supervision and hands-on training. This approach can strengthen competency-based learning and better prepare students for safe workplace practices.

Technology education in the Philippine context

The study demonstrates the potential of AR to support the modernization of competency-based technical-vocational education in the Philippines. By integrating technical skills with occupational health, ergonomics, environmental safety, and digital learning, AR can enhance students' workplace readiness and align training with current industry demands. Its adoption in Automotive Servicing NC II may contribute to producing technically competent, digitally skilled, safety-conscious, and environmentally responsible graduates, supporting ongoing innovations in Philippine technology education.

CONCLUSION

This study demonstrated that Augmented Reality (AR)-supported instruction is an effective supplementary approach for enhancing competency-based learning in Automotive Servicing NC II. Students who received AR-supported instruction achieved greater improvements in automotive competency, occupational health and safety, ergonomic practices, and environmental safety than those who received conventional instruction. The qualitative findings further indicated that AR improved procedural understanding, hazard recognition, ergonomic awareness, environmental responsibility, and learner engagement. Collectively, these findings suggest that AR extends beyond technical skills training by integrating occupational health, ergonomics, and environmental safety into authentic workshop learning. Therefore, AR-supported instruction has strong potential to produce technically competent, safety-conscious, ergonomically responsible, and environmentally responsible Automotive Servicing NC II graduates.

RECOMMENDATIONS

Based on the findings, Augmented Reality (AR) is recommended as a supplementary instructional strategy in Automotive Servicing NC II to strengthen technical competency alongside occupational health, ergonomic awareness, and environmental safety. AR modules should integrate contextual guidance on hazard recognition, PPE use, proper body mechanics, and environmentally responsible workshop practices. Institutions should provide adequate instructor training, technical support, and infrastructure to facilitate effective implementation. Future studies should involve larger, multi-institutional samples and longer intervention periods to evaluate the long-term effectiveness of AR-supported instruction and explore its integration with emerging technologies such as artificial intelligence and adaptive learning systems.

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