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ORIGINAL

Enhancing Hospitality Competencies: The Role of Mobile Augmented Reality In Indonesian Vocational Schools

Mejorando las competencias en hospitalidad: El papel de la realidad aumentada móvil en las escuelas vocacionales de Indonesia

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ABSTRACT

The integration of immersive technologies such as augmented reality (AR) in tourism and hospitality education remains limited, particularly in developing countries like Indonesia, where textbook-based instruction often restricts student engagement and practical skill development, leaving gaps in spatial, procedural, and conceptual competencies. This study examined the effectiveness of mobile AR applications in improving hospitality competencies and explored gender-based differences in learning outcomes among vocational school students. A quasi-experimental design was implemented with 420 eleventh-grade students from four vocational schools over eight weeks, where the experimental group used AR to simulate hotel operations while the control group received textbook-based instruction. Hospitality Competency Test scores were analyzed using ANCOVA controlling for pre-test scores, and qualitative data from semi-structured interviews were thematically analyzed to complement the quantitative results. Findings showed a significant positive effect of AR on overall competency ($F(1,417)=175,36$, $p<0,001$, $\eta p^2=0,296$; Cohen's $d=1,18$), with higher post-test performance in spatial awareness, procedural knowledge, and conceptual understanding. A significant gender-by-intervention interaction ($F(1,415)=5,04$, $p=0,025$, $\eta p^2=0,012$) indicated that females in the AR group achieved greater gains in procedural knowledge ($d=0,43$) and spatial learning. Qualitative findings reinforced these outcomes, revealing increased engagement, collaboration, and comprehension of complex service processes, with only minor technical challenges. These results suggest that AR can be effectively integrated into competency-based vocational curricula to accelerate skill acquisition, enhance engagement, and promote gender equity in hospitality training, provided that adequate infrastructure and teacher professional development are ensured. Future research should include multi-site longitudinal studies to assess retention, workplace transfer, cost-effectiveness, and the potential benefits of integrating AR with VR, AI, and learning analytics for scalable implementation.

Keywords: Augmented Reality; Hospitality Competencies; Vocational Education; Immersive Learning; Gender Equity; Employability Skills.

RESUMEN

La integración de tecnologías inmersivas como la realidad aumentada (RA) en la educación en turismo

y hospitalidad sigue siendo limitada, especialmente en países en desarrollo como Indonesia, donde la enseñanza basada en libros de texto suele restringir la participación de los estudiantes y el desarrollo de habilidades prácticas, generando brechas en las competencias espaciales, procedimentales y conceptuales. Este estudio examinó la efectividad de las aplicaciones de RA móvil para mejorar las competencias en hospitalidad y exploró las diferencias de aprendizaje según el género entre estudiantes de escuelas vocacionales. Se implementó un diseño cuasi-experimental con 420 estudiantes de undécimo grado de cuatro escuelas vocacionales durante ocho semanas, en el que el grupo experimental utilizó RA para simular operaciones hoteleras, mientras que el grupo de control recibió instrucción basada en libros de texto. Las puntuaciones del Test de Competencias en Hospitalidad se analizaron mediante ANCOVA controlando los puntajes de pretest, y los datos cualitativos de entrevistas semiestructuradas se analizaron temáticamente para complementar los resultados cuantitativos. Los hallazgos mostraron un efecto positivo significativo de la RA sobre la competencia general ($F(1,417)=175,36$, $p<0,001$, $\eta p^2=0,296$; d de Cohen=1,18), con un mejor desempeño en la prueba posterior en conciencia espacial, conocimiento procedimental y comprensión conceptual. Una interacción significativa entre género e intervención ($F(1,415)=5,04$, $p=0,025$, $\eta p^2=0,012$) indicó que las estudiantes del grupo de RA lograron mayores avances en conocimiento procedimental (d=0,43) y aprendizaje espacial. Los hallazgos cualitativos reforzaron estos resultados, revelando mayor compromiso, colaboración y comprensión de procesos de servicio complejos, con solo desafíos técnicos menores. Estos resultados sugieren que la RA puede integrarse de manera efectiva en planes de estudio vocacionales basados en competencias para acelerar la adquisición de habilidades, mejorar la participación y promover la equidad de género en la formación en hospitalidad, siempre que se garantice la infraestructura adecuada y la capacitación docente. Futuros estudios multicéntricos y longitudinales deberían evaluar la retención, la transferencia al lugar de trabajo, la rentabilidad y los beneficios potenciales de combinar la RA con la realidad virtual, la inteligencia artificial y la analítica del aprendizaje para una implementación escalable.

Palabras clave: Realidad Aumentada; Competencias en Hospitalidad; Educación Vocacional; Aprendizaje Inmersivo; Equidad de Género; Competencias para la Empleabilidad.

INTRODUCTION

The development of information and communications technology (ICT) has been one of the most significant milestones in transforming education, enabling interactive and learner-centered approaches that enhance engagement and performance.[1] Among these innovations, augmented reality (AR) has gained increasing attention for its ability to integrate real-life contexts with layers of digital content, providing learners with immersive experiences that bridge theory and practice.[2] In vocational and hospitality education, where both conceptual knowledge and procedural skills are essential, AR offers unique opportunities to enhance students' competencies by simulating authentic environments.[3] AR also allows learners to practice operational tasks such as room preparation, food service, and hygiene procedures in safe and controlled spaces, making skill acquisition more efficient.[4]

The pedagogical effectiveness of AR is supported by embodied cognition theory, which posits that learning improves when students physically and cognitively interact with their environment, making AR particularly relevant for hospitality education where procedural and spatial skills are critical.[5] Cognitive load theory (CLT) further explains that AR can reduce extraneous cognitive load by presenting complex procedures in interactive, segmented steps, allowing students to focus on key learning tasks.[6] Evidence from vocational training research shows that AR-based instruction can simplify service procedures into manageable steps, improving conceptual understanding and procedural accuracy.[7]

In Indonesia, vocational schools play a crucial role in preparing a skilled workforce for the hospitality industry, but teaching remains largely teacher-centered, relying heavily on textbooks and lectures and limiting opportunities for hands-on practice.[8] Empirical studies in occupational safety, technical certification, and engineering education have demonstrated that AR improves visualization, retention, and spatial reasoning, suggesting its potential to enhance hospitality education quality, particularly in resource-constrained schools where access to real-world training facilities is limited.[9,10]

Despite its promise, AR adoption faces challenges such as limited access to devices and infrastructure, particularly in rural areas, as well as a lack of teacher readiness to integrate AR effectively.[11] Gender disparities further complicate this challenge, as female students are often the majority in hospitality programs but have been shown to underperform in spatial and procedural tasks, which hinders equitable skill development.[12] Research in STEM education suggests that AR can help narrow gender gaps by providing scaffolding and interactive visualizations that enhance spatial learning.[13]

Although interest in AR is growing, most previous studies focus on short-term learning outcomes and STEM-related contexts, with relatively few addressing hospitality education, long-term retention, workplace transfer,

or cost-effectiveness. Few studies explicitly examine gender-differentiated outcomes in AR-based learning. [11,12,13] These gaps highlight the need for robust empirical research that investigates AR's impact on multiple competency domains and its potential to promote equitable learning outcomes.

Accordingly, the primary objective of this study is to examine the impact of mobile AR applications on hospitality students' spatial awareness, procedural knowledge, and conceptual understanding compared with textbook-based teaching, and to determine whether AR can promote gender equity by narrowing disparities between male and female students in vocational hospitality training.

METHOD

Research design

This study adopted a quasi-experimental design to examine the effects of mobile AR applications on the hospitality competencies of vocational school students in Indonesia by comparing an experimental group using AR applications with a control group receiving conventional textbook-based instruction, both following the same syllabus, duration, and learning objectives. The AR applications replicated core areas of hospitality training, including front office operations (e.g., digital check-in and check-out procedures with virtual customers), housekeeping tasks (e.g., room preparation, bed making, bathroom cleaning), food and beverage service procedures (e.g., table setting, order taking, service sequence), and hygiene and safety protocols (e.g., interactive cues for sanitation standards and SOP compliance), enabling students to engage in interactive, practice-oriented tasks in safe virtual environments. The control group participated in structured classroom sessions consisting of teacher-led lectures, textbook reading, chalkboard explanations, printed handouts, and verbal questioning to reinforce key concepts, with students taking notes, answering questions, and completing brief written exercises; no videos, digital media, or interactive demonstrations were used. This quasi-experimental approach allowed systematic comparison between groups while controlling for variables such as academic background and gender, and to minimize treatment contamination, experimental and control classes were scheduled on different days and taught by different instructors using a common syllabus and assessment criteria.

Sample description

The participants comprised 420 eleventh-grade students (aged 16–17 years; M = 16,5; SD = 0,5) from four vocational high schools specializing in hospitality programs across West Sumatra, Indonesia. A stratified random sampling technique was employed to ensure representation across geographic and socio-economic backgrounds. Of the total sample, 51,0 % were female and 49,0 % were male. In terms of location, 54,3 % of students were from urban areas and 45,7 % from rural settings. Socio-economic status (SES) was determined based on parental occupation and income, resulting in 22,1 % high-SES, 50,5 % medium-SES, and 27,4 % low-SES participants. Pre-intervention surveys indicated that fewer than 15 % of students had prior experience with AR technology, suggesting a comparable baseline of technological exposure across groups. Table 1 summarizes the demographic characteristics of the participants.

Inclusion criteria required active enrollment in the grade-11 hospitality track, ≥ 75 % attendance during the eight-week intervention, written parental consent and student assent, and completion of both pre- and post-intervention HCT assessments. Assignment to conditions was conducted at the class (cluster) level rather than individually. To reduce potential instructor- and class-related confounding effects, classes assigned to the AR and control conditions were matched on class size and student composition, taught using a common syllabus, and assessed using identical rubrics. Instructors from both groups received a standardized pre-intervention orientation and written teaching guidelines to ensure consistent delivery aligned with the study protocol. All instructors had comparable teaching experience. Nevertheless, potential teacher/class effects are acknowledged and discussed in the Limitations section.

Table 1. Participant demographics

Demographic Characteristics	Experimental Group (n = 210)	Control Group (n = 210)	Total (N = 420)
Gender	Female: 107 (51,0 %) Male: 103 (49,0 %)	Female: 107 (51,0 %) Male: 103 (49,0 %)	Female: 214 (51,0 %) Male: 206 (49,0 %)
Location	Urban: 114 (54,3 %) Rural: 96 (45,7 %)	Urban: 114 (54,3 %) Rural: 96 (45,7 %)	Urban: 228 (54,3 %) Rural: 192 (45,7 %)
Socio-economic Status	High: 46 (22,1 %) Medium: 106 (50,5 %) Low: 58 (27,4 %)	High: 46 (22,1 %) Medium: 106 (50,5 %) Low: 58 (27,4 %)	High: 92 (22,1 %) Medium: 212 (50,5 %) Low: 116 (27,4 %)
Mean Age (years) ± SD	16,5 ± 0,5	16,5 ± 0,5	16,5 ± 0,5

Instruments

In order to assess students' hospitality competencies, the Hospitality Competency Test (HCT) was developed as a 40-item multiple-choice instrument based on the Indonesian vocational hospitality curriculum and aligned with established competency assessment frameworks.[1] The HCT covered three domains: spatial awareness in hospitality operations (14 items), procedural knowledge of service tasks (13 items), and conceptual understanding of hospitality standards (13 items). The internal consistency of the test was high (Cronbach's α = 0,88), and additional procedures were implemented to ensure its validity.

Content validity was established through expert review by five hospitality educators and two psychometricians, who evaluated item clarity, relevance, and alignment with expected learning outcomes. Their feedback informed revisions that enhanced clarity and applicability. A pilot study involving 100 students was conducted, and data were analyzed using item response theory (IRT) and confirmatory factor analysis (CFA) to examine item difficulty and discrimination following psychometric guidelines.[2] The final version demonstrated good model fit for the three-factor model (CFI = 0,94; RMSEA = 0,05), confirming that the HCT effectively captured the intended constructs. Pre- and post-test scoring was conducted independently by two trained assessors who were blinded to participants' group allocation (experimental vs. control) to minimize scoring bias. Inter-rater agreement was reviewed and considered acceptable based on consensus between assessors.

The Student Perception Questionnaire (SPQ) was a 20-item standardized self-report instrument adapted from validated scales measuring perceived usefulness, perceived ease of use, and perceived learning in AR-enhanced education.[3,4,5] Content validity was confirmed through expert review, followed by pilot testing and item analysis, which yielded high internal reliability (α = 0,90).

Additionally, qualitative data were collected through semi-structured interviews with a purposive sample of 40 students (20 AR group, 20 control group). The interview protocol was designed to elicit students' reflections on their learning experiences, perceived difficulties with the teaching methods, and perceived benefits of AR applications. Data were analyzed thematically following Braun and Clarke's six-phase framework,[6] providing deeper contextual insights and triangulating the quantitative findings.

Data collection procedures

Quantitative data

Pre-test: all participants completed the Hospitality Competency Test (HCT) one week before the intervention.

Intervention: the eight-week intervention period followed, with the experimental group using the AR application to simulate core hospitality operations. The AR group received two 90-minute sessions per week over 8 weeks (≈24 hours of AR-supported practice), whereas the control group followed the same lesson plans without AR. The application included front office simulations (check-in and check-out procedures with virtual customers), housekeeping simulations (room preparation, bed making, and bathroom cleaning), food and beverage service simulations (table setting, order taking, and service sequence), and hygiene and safety procedures (interactive visual cues for sanitation and compliance with SOPs). To ensure implementation fidelity, teachers in the AR condition completed a 6-hour training on app operation, troubleshooting, and classroom management with AR; sessions used school-issued devices (Android 11+ with ≥4 GB RAM) on a 1:1 basis. Attendance, time-on-task, and completion of in-app activities were logged each session, and a brief weekly fidelity checklist was completed by an observer. To minimize treatment contamination, AR and control classes were timetabled separately and taught by different instructors using a common syllabus.

Post-test: the HCT was administered to all participants one week after the intervention to measure learning gains.

SPQ: immediately after the post-test, the experimental group completed the Student Perception Questionnaire (SPQ) to evaluate perceived usefulness, ease of use, and learning.

Qualitative data

Semi-structured interviews were conducted with a purposive subset of 40 students (20 from each group) selected through maximum variation sampling to ensure diverse perspectives in terms of gender, socio-economic background, and school location. Interviews lasted approximately 30 minutes each and were audio-recorded for transcription and thematic analysis. The interview protocol included questions about learners' experiences with AR features, perceived advantages and challenges of using AR in hospitality training, and comparisons with conventional methods.

Data Analysis

Quantitative analysis

The quantitative data were analyzed in IBM SPSS Statistics 26 with α = .05 (two-tailed).[5,12,15] Independent-samples t-tests and analyses of covariance (ANCOVAs) were conducted to compare the experimental and control groups. ANCOVA was used to estimate the effect of the AR intervention on hospitality competencies

while statistically controlling for pre-test scores, thereby adjusting for baseline differences, reducing error variance, and increasing the precision of treatment effect estimates.[14,15] In addition to omnibus tests, domain-specific comparisons (spatial awareness, procedural knowledge, conceptual understanding) were examined. Effect sizes are reported as partial eta squared (ηp^2) for ANCOVAs and Cohen's d for t-tests, accompanied by 95 % confidence intervals for adjusted means and effect sizes.[16] Pairwise comparisons were Bonferroni-adjusted where applicable.

All ANCOVA assumptions were evaluated prior to inference: (a) homogeneity of regression slopes was tested via the Group × Pre-test interaction (nonsignificant indicates the assumption holds); (b) normality of residuals was inspected using Q–Q plots and Shapiro–Wilk tests on model residuals within groups; (c) homogeneity of variances was assessed with Levene's test; and (d) linearity between the covariate and each dependent variable was checked via scatterplots and partial regression plots. Independence was supported by the class-level assignment and separate timetabling. Missing data were <3 % across variables; Little's MCAR test indicated data were missing completely at random, and listwise deletion was applied for primary analyses. Univariate outliers (>3 SD from the mean) were winsorized, and influential cases (Cook's D > 4/n) were examined; sensitivity analyses with and without these cases yielded substantively similar results. A priori power analysis ($\alpha = 0,05$, $1-\beta = 0,80$) indicated that the achieved sample (N = 420) afforded adequate power to detect small-to-medium main effects (approx. $f \geq 0,15$) and small interaction effects (approx. $f \geq 0,10$) in the two-way ANCOVA with one covariate.

Qualitative analysis

Interview data from the semi-structured protocol were analyzed using thematic analysis following Braun and Clarke's six-step approach (familiarization, initial coding, theme development, review, definition, and reporting).[17] Transcripts were coded independently by two researchers using an agreed codebook; intercoder agreement (Cohen's κ) indicated substantial reliability, and discrepancies were resolved through discussion to consensus. An audit trail was maintained to enhance dependability, and triangulation with quantitative findings was used to corroborate and elaborate the emergent themes on engagement, procedural learning, and spatial skill development.

RESULTS

Quantitative findings

Impact of AR on hospitality competencies

A one-way ANCOVA was conducted to determine the effect of the AR intervention on overall hospitality competencies, controlling for pre-test scores. The results revealed a significant main effect of the intervention, $F(1, 417) = 175,36$, $p < 0,001$, $\eta^2 = 0,296$. The AR group ($M = 8,3$, $SD = 1,2$) significantly outperformed the control group ($M = 6,7$, $SD = 1,3$), with a large effect size (Cohen's $d = 1,18$). These findings demonstrate that AR applications had a substantial impact on students' hospitality competencies, particularly in complex domains such as procedural knowledge of service tasks and spatial awareness in hotel operations.

Table 2. Comparison of hospitality competency domains between AR and control groups

Domain	AR Group (n = 210)	Control Group (n = 210)	F	p	ηp^2	Cohen's d [95 % CI]
Spatial Awareness	8,4 (1,2)	6,8 (1,3)	162,42	<0,001	0,280	1,13 [0,94, 1,32]
Procedural Knowledge	8,2 (1,1)	6,6 (1,4)	189,73	<0,001	0,313	1,25 [1,06, 1,44]
Conceptual Understanding	8,3 (1,0)	6,7 (1,3)	171,65	<0,001	0,292	1,20 [1,01, 1,39]

Note: values are adjusted means (EMMs) controlling for pretest. Effect sizes are partial eta squared (ηp^2). Assumptions for ANCOVA were met.

Table 2 shows that the AR group consistently outperformed the control group across all competency domains. The largest effect size was observed for procedural knowledge ($d = 1,25$), suggesting that AR applications are particularly effective in enhancing students' mastery of service-related tasks. Effect sizes above 0,80 are considered large according to established guidelines,[3] suggesting that the observed differences represent a strong and practically meaningful impact of AR on student learning.

To complement the statistical results, a bar chart (figure 1) was created to visualize the mean score differences between the AR and control groups across the three competency domains. This visual representation reinforces the finding that AR consistently produced higher learning outcomes, with the most notable gain in procedural knowledge.

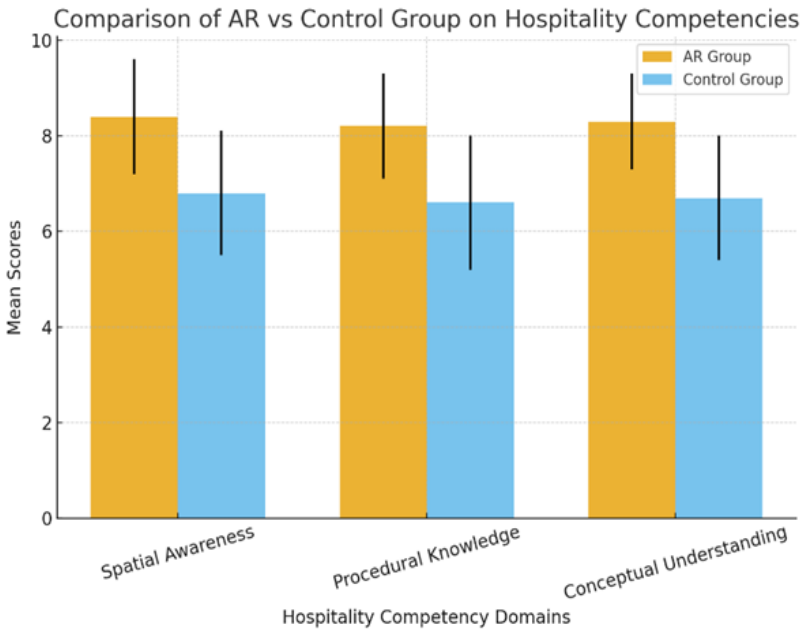

Figure 1. Adjusted mean scores (±95 % CI) by competency domain for AR vs. control groups

Gender differences in AR effectiveness

A two-way ANCOVA was conducted to explore the interaction between gender and intervention type on hospitality competencies, controlling for pre-test scores. Results indicated a significant main effect of intervention, $F(1, 415) = 168{,}41$, $p < 0{,}001$, $\eta^2 = 0{,}289$; a small but significant main effect of gender, $F(1, 415) = 7{,}12$, $p = 0{,}008$, $\eta^2 = 0{,}017$; and a significant interaction between gender and intervention type, $F(1, 415) = 5{,}04$, $p = 0{,}025$, $\eta^2 = 0{,}012$.

Post-hoc analyses with Bonferroni correction revealed that female students in the AR group ($M = 8{,}6$, $SD = 1{,}0$) showed significantly greater improvement in procedural knowledge compared to their male counterparts ($M = 8{,}1$, $SD = 1{,}1$), $t(208) = 3{,}12$, $p = 0{,}002$, Cohen's $d = 0{,}43$.

Table 3. Gender comparison of hospitality competency domains in AR group

Domain	Females (n = 107)	Males (n = 103)	t	p	Cohen's d [95 % CI]
Spatial Awareness	8,7 (1,1)	8,2 (1,2)	2,61	0,010	0,36 [0,09, 0,63]
Procedural Knowledge	8,6 (1,0)	8,1 (1,1)	3,12	0,002	0,43 [0,16, 0,70]
Conceptual Understanding	8,5 (1,1)	8,0 (1,2)	2,77	0,006	0,38 [0,11, 0,65]

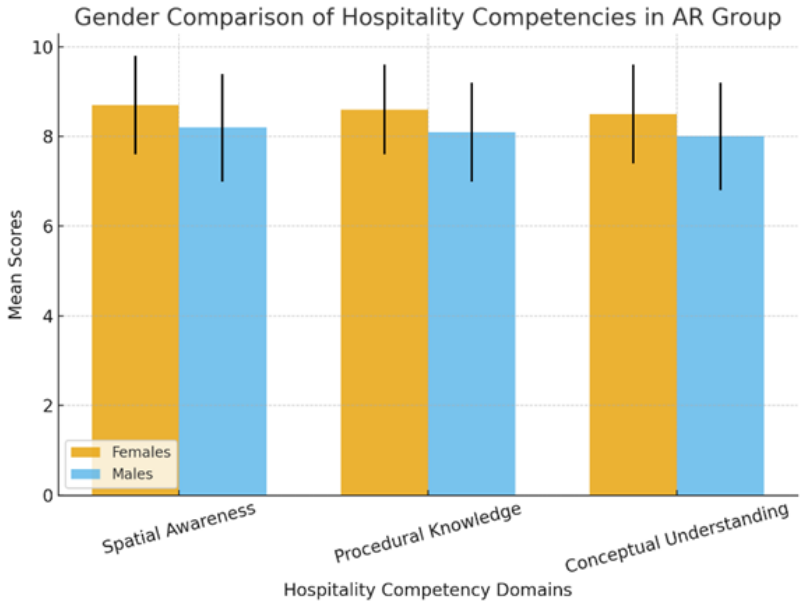

Figure 2. Adjusted mean scores (±95 % CI) by gender in the AR group across competency domains

The gender-specific results indicate that AR applications not only improved overall hospitality competencies but also contributed to reducing gender gaps in procedural and spatial learning. Female students, who often underperform in these areas, benefitted more from AR's interactive and experiential environment. This finding resonates with prior research suggesting that AR can provide cognitive scaffolds that are particularly beneficial for female learners in tasks requiring spatial reasoning.[9,18] By providing interactive, embodied experiences, AR helps mitigate traditional gender-based disparities in procedural and spatial tasks, which are critical for vocational success in hospitality.

Student perceptions of AR learning experience

Analysis of the SPQ revealed high levels of engagement and perceived learning benefits among AR group participants. The mean overall satisfaction score was 4,3 out of 5 (SD = 0,5).

Table 4. Student perceptions of AR learning experience

Dimension	Mean (SD)
Engagement	4,6 (0,4)
Ease of Use	4,1 (0,6)
Perceived Learning Benefits	4,4 (0,5)
Motivation to Learn Hospitality	4,5 (0,4)

These findings suggest that AR enhanced students' overall learning experience. High scores in engagement, perceived benefits, and motivation indicate that AR makes learning more enjoyable, practical, and relevant, especially in vocational hospitality training.

Qualitative findings

Thematic analysis of the semi-structured interviews revealed four main themes:

1. Enhanced visualization and procedural understanding: students consistently reported that AR helped them better understand hospitality processes. One student noted, "Practicing check-in with AR made me feel like I was really in the hotel lobby" (student 14, female). This aligns with the quantitative findings, where procedural knowledge and spatial awareness showed significant improvement in the AR group. Several female students highlighted that AR made it easier to grasp spatially complex tasks, supporting the quantitative evidence of their greater gains compared to males.
2. Increased engagement and motivation: many students expressed heightened interest in hospitality learning due to the AR experience. A male student stated, "It felt like I was already working in a hotel. It makes me more excited to learn" (student 9, male). These qualitative insights suggest that AR not only improves academic outcomes but also fosters a more engaging and enjoyable learning experience, which could have long-term benefits for student motivation in vocational training. Notably, female participants frequently mentioned feeling more confident and motivated when completing procedural tasks, reinforcing the gender-specific findings from the quantitative analysis.
3. Collaborative learning opportunities: the AR application facilitated peer-to-peer learning. A female student observed, "We often practiced the AR scenarios together, sharing tips and correcting each other" (student 21, female). This indicates that AR technology can create collaborative learning environments, an important aspect of modern vocational education that emphasizes teamwork and communication skills. The collaborative element also reflects the hospitality industry's emphasis on interpersonal competence, making AR a valuable complement to existing training practices.
4. Technical challenges and learning curve: some students reported initial difficulties in using the AR application. "At first, it was confusing, but once I got used to it, it was really helpful" (student 12, male). This highlights the importance of providing adequate support and training for both students and teachers to maximize the potential of AR in vocational settings. While these issues were relatively minor, they point to the infrastructural and pedagogical support required for broader AR adoption.

Overall, the findings support the hypothesis that AR applications improve students' hospitality competency profiles, particularly in spatial awareness and procedural knowledge. These qualitative insights triangulate well with the quantitative results, showing that AR complements conventional teaching methods by offering hands-on, immersive experiences. From a practical perspective, AR was also found to enhance gender-specific outcomes, particularly for female students, suggesting that it can play a role in reducing disparities in vocational education. For educators and policymakers, these findings underline the need to integrate AR as an instructional tool and invest in teacher training, reliable infrastructure, and user-friendly applications to ensure sustainable

implementation. Two researchers independently coded all transcripts using a shared codebook; intercoder agreement was substantial (Cohen's κ = ,79), and discrepancies were resolved by discussion to consensus.

DISCUSSION

This study investigated the impact of mobile AR applications on the hospitality competencies of Indonesian vocational school students. The results suggest that AR may enhance students' spatial awareness, procedural knowledge, and conceptual understanding, with notable gains among female students in procedural and spatial tasks. Under the conditions of this eight-week intervention, AR showed potential as an effective pedagogical tool for vocational training, providing valuable insights for both theory and practice in hospitality education.

The findings indicate that AR can bridge the gap between theoretical knowledge and practical application by enabling students to visualize, manipulate, and practice tasks such as check-in procedures, restaurant table settings, and housekeeping routines in an interactive 3D environment. This is consistent with embodied cognition, which argues that learning is strengthened when learners physically and cognitively interact with their environment.[10] Gains in spatial awareness are predicted by embodied interaction (e.g., rotating or scaling 3D objects), improvements in procedural knowledge align with cognitive load theory through stepwise task segmentation and worked examples, and conceptual understanding gains reflect multimedia learning principles such as signaling and modality that reduce extraneous load.[11,12]

From a gender perspective, the results indicate that AR may contribute to reducing performance gaps between male and female students, especially in spatial and procedural competencies where female students have traditionally been at a disadvantage. Beyond spatial scaffolding, this effect may also be linked to reduced stereotype threat, as AR provides a low-stakes, interactive environment that enhances confidence and mitigates performance anxiety for female learners. Prior research has shown that stereotype threat can depress women's performance on spatial and math tasks, whereas supportive and mastery-oriented learning contexts can help mitigate these effects.[20,21] Future research should investigate whether AR interventions can systematically reduce stereotype threat and improve self-efficacy across genders.

Importantly, the success of AR interventions depends not only on the technology but also on the teacher's pedagogical role in integrating it into classroom practice. Teachers facilitate reflection, connect virtual simulations to real-world procedures, and promote collaborative learning. These findings highlight the need for teacher professional development that includes technical training on AR use, lesson design aligned with learning objectives, and strategies for fostering teamwork and peer communication during AR-based practice sessions.

The results also underscore the importance of addressing infrastructure and implementation issues. Some students reported initial difficulties in using AR applications, emphasizing the need for adequate devices, stable internet connectivity, and troubleshooting support. Teacher training should incorporate AR-aligned lesson planning, device management, and simple fidelity checklists to ensure that AR use remains pedagogically purposeful rather than novelty-driven. The high satisfaction scores observed in the SPQ may partly reflect a novelty effect associated with the first-time use of AR. Such novelty effects may diminish as students become accustomed to the technology, underscoring the need for longitudinal research to examine whether engagement and learning gains persist across multiple semesters or repeated exposures.[22]

While these findings are promising, several limitations should be considered. Assignment to conditions was conducted at the class (cluster) level, which introduces potential teacher and class effects. Although a common syllabus and teacher orientation were used to standardize instruction, residual clustering cannot be ruled out. The study was conducted in four vocational schools within a single province, which constrains generalizability across Indonesia's diverse curricula and resource profiles. In addition, while the HCT demonstrated good reliability and fit, it was aligned to the local curriculum and requires further validation for broader use. Finally, device performance and network stability were not systematically compared across sites, and teachers' digital competence was not measured as a moderator.

Future research should extend these findings by using cluster-randomized designs with multilevel modeling to account for classroom nesting effects and report ICCs. Longitudinal studies with delayed post-tests (e.g., 3- and 6-month follow-ups) and performance-based assessments (e.g., rubric-scored service tasks, internship supervisor ratings) are needed to examine retention and transfer of learning to workplace performance. Comparative studies across urban vs. rural schools, public vs. private institutions, and cross-national contexts would clarify contextual opportunities and constraints for AR adoption. Further, research should explore adaptive AR pathways powered by AI and learning analytics to personalize task segmentation, just-in-time hints, and feedback based on performance data.[23] Finally, cost-effectiveness, scalability, and equity analyses should be conducted, including testing low-cost/offline AR variants, to inform sustainable adoption in resource-constrained vocational settings.

CONCLUSIONS

This study provides empirical evidence—from a quasi-experimental design—that mobile AR applications

can enhance vocational hospitality learning outcomes in the short term. Students who engaged with AR outperformed their peers in spatial awareness, procedural knowledge, and conceptual understanding; moreover, female students showed comparatively larger gains on spatial and procedural tasks, suggesting AR's potential to narrow gender gaps in vocational learning. These findings should be interpreted alongside the study's scope and duration and are best viewed as evidence of near-term instructional benefits rather than definitive proof of long-term impact.

Beyond classroom practice, the results have practical and policy implications for vocational training in Indonesia. As the system advances its digital transformation, AR is a promising tool to bridge learning gaps, strengthen motivation, and cultivate competencies required in hospitality—particularly when paired with sound pedagogy and reliable infrastructure. At a system level, ministries and districts could pilot coordinated procurement of minimum-spec devices, fund tiered teacher professional development for AR-aligned lesson design, and establish national or provincial licensing (or open repositories) for vetted AR content mapped to the hospitality curriculum, while monitoring equity, cost-effectiveness, and data privacy. Addressing disparities in connectivity, hardware, and teacher readiness will be essential for scalable and equitable integration.

Finally, further research is warranted to determine durability and transfer of AR-enabled competencies: studies should examine multi-month retention, on-the-job performance during internships, and impacts on career intentions across diverse institutional and cultural contexts. Comparative and multi-site, cluster-randomized trials—paired with cost and implementation analyses—would clarify scalability. In addition, combining AR with virtual reality (VR), artificial intelligence (AI), and gamification may enable more immersive and personalized pathways; rigorous evaluations should test these hybrids against clear learning objectives. With careful attention to evidence, scale, and equity, AR can contribute meaningfully to transforming vocational education and preparing graduates for success in an increasingly digital and globalized service economy.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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