Received: 12 June 2026 | Revised: 7 September 2026 | Accepted: 14 October 2026 | Published online: 11 November 2026

RESEARCH ARTICLE

Artificial Intelligence and Applications
2026, Vol. 00(00) 1–14
DOI: 10.47852/bonviewAIA620210834

BON VIEW PUBLISHING

Bridging Engagement and Behavioral Performance in Immersive Virtual Reality: The Role of Interaction Design and Cultural Context

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Abstract: Immersive virtual reality (VR) integrates both experiential and procedural training like no other technology, providing exceptional opportunities in vocational education. Specifically, in the teaching/learning process, VR incorporates the modeling of real-world environments, powerful interactive 3D graphics, and computer simulation. The impact on the behavior of users is underexplored. The current study attempts to bridge this gap by developing the Integrated Behavioral Evaluation Framework (IBEF). This new framework is built upon the behavioral concepts of immersive systems, User Engagement, behavioral accuracy, procedural competence, and behavioral interpretation. An explanatory quantitative research design was adopted with a sample of 120 vocational education students who had undergone immersive VR-based training in table manners. High User Engagement did not translate into procedural accuracy in execution. Participants' engagement was impacted more by the procedural setting than the design of the immersive VR-based dining simulation. The results of the current study reaffirm that behavioral execution, especially in culturally moderated scenarios, is impacted by the digital readiness of the user and their behavioral frameworks. The IBEF provides an extended evaluation framework for immersive learning compared to existing frameworks by merging the contextual interpretation of behavioral actions and subjective psychological components. This evaluation framework offers an in-depth understanding of procedural instruction in immersive learning environments. It is of value to educators, instructional designers, and VR developers. The framework proposed may extend beyond hospitality education and assist with the evaluation of immersive learning across other areas of vocational education, healthcare simulation, engineering training, or other fields involving the development of procedural skills.

Keywords: immersive virtual reality, human–computer interaction, user engagement, behavioral performance, user experience

1. Introduction

The use of immersive technologies in digital learning [1, 2], especially in fields that develop skills through repetition and practice, is among the many advancements in technology that have improved the learning process [3–5]. As an emerging technology in education, immersive virtual reality (VR) is being used by more educators who aim to facilitate experiential learning. VR allows users to immerse themselves in virtual worlds that simulate real-life environments [6–8]. Unlike standard computer-based learning, immersive VR allows users to practice procedural skills an unlimited number of times through real-time manipulation of virtual objects and receive immediate input and feedback [9–11]. This takes place in a controlled environment. This makes VR an ideal instructional technology for numerous fields, such as education, healthcare, engineering, and hospitality [12–15], which require the development of practical and behavioral skills.

The use of educational technologies in past research has shown that immersive VR consistently improves learner motivation, engagement, presence, and perceived learning [16, 17]. These

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improved qualities have typically been the result of the VR simulations' presence, interactivity, and realism [18]. These qualities have also been the result of the cognitive effort and engagement of the VR learning participants [19, 20]. Because of this, User Engagement has been the most common parameter used to measure instructional design and the learning systems created through immersive technologies.

Although this has somewhat been improved, the focus in evaluating immersive learning systems in the context of learning remains dominated by subjective measures of User Engagement, satisfaction, and technology acceptance [21, 22]. These measures provide some insight into the user learning experience but do not describe the actual procedural learning outcome in the immersive simulation [23]. In the skill-based educational fields, such user evaluations have little value when the aim of the educational practice is to enable and measure the actual procedural outcomes in the real context of work.

Limitations are clear in procedural learning that includes behavioral components, such as hospitality and formal dining etiquette. Learning participants have reported high engagement levels, while simultaneously displaying procedural errors as a result of ingrained habits, cultural patterns, and erroneous behavior transfer. As a result, focusing on questionnaire-based assessments may skew results and indicate that immersive learning systems have a positive impact, as expressed engagement does not correlate with procedural accuracy.

In recent years, some immersive learning studies have started to employ learning analytics and performance measurement [24]. However, most existing assessment methods still focus on the subjective measurement of engagement and the behavioral performance assessment separately [25]. Only a few studies have attempted to construct an integrated method that allows the simultaneous assessment of the immersive experience, User Engagement, and objective behavioral performance in the context of a unified competence assessment model. As such, the impact of immersive interaction on procedural competence is still poorly articulated.

New research in educational technology is severely lacking in this area and focuses mainly on whether learners appreciate the immersion of different VR designs. Very little research attention has focused on the actual behavioral procedures stemming from immersion. Without behavioral procedures, current assessment methods remain partial in the measurement of learning impact in vocational training.

To address this gap, an integrated evaluation framework of immersive vocational learning is proposed, combining the evaluation of subjective engagement with the analysis of objective behavioral performance and procedural competence. This new framework understands immersive VR experience in terms of three dimensions—immersion, interactivity, and realism. Procedural competence is influenced by User Engagement and can be assessed using this framework. Unlike previous studies that have relied on evaluation through questionnaires, the proposed framework includes an analysis of the behavioral accuracy of learners and provides an objective assessment of the enactment of procedures through immersive dining simulations. This framework makes it possible to evaluate the immersive learning experience in a much more integrated way, combining psychological engagement with measurable behavioral engagement.

The originality of the proposed Integrated Behavioral Evaluation Framework (IBEF) lies in its integration of subjective and objective evidence within a single evaluation logic for immersive procedural learning. Conventional VR learning evaluations frequently emphasize experiential constructs such as immersion, presence, engagement, usability, and perceived learning outcomes. Although these constructs are important for understanding learners' experiences, they do not necessarily demonstrate whether learners can accurately execute the target procedures. IBEF addresses this limitation by linking VR experience characteristics and User Engagement with Interaction Performance in the Table Manners Context while simultaneously incorporating behavioral observation and behavioral accuracy. This integration enables the evaluation to distinguish between what learners perceive and report about their performance and what they actually perform during procedural tasks.

Accordingly, the contribution of IBEF is methodological rather than merely technological. The framework provides an integrated evaluation logic for immersive procedural learning in which psychological engagement and observable behavioral performance are examined as complementary sources of evidence. This distinction is particularly relevant to vocational education, where successful learning requires not only positive learning experiences but also accurate execution of task-specific procedures.

Considering the context of educational technology, this study will have three key areas of contribution. First, the study will contribute an integrated methodology that allows for the evaluation of immersive vocational training involving the dual elements of subjective engagement and behavioral performance. Second, this research pushes the boundaries for the evaluation of immersive learning by accounting for the behavioral accuracy of users and demonstrating that high levels of User Engagement do not automatically result in comparable levels of procedural accuracy. Finally, this study has the potential to provide a framework for the design of culturally responsive instructional design and systems of immersive vocational training in view of the influence of cultural behavioral schemas on procedural performance of users in immersive VR space.

2. Literature Review and Hypothesis Development

2.1. Immersion and presence in virtual reality interaction

Immersion is a fundamental component of VR systems and enables the measurement of how much a user experiences a virtual environment as being present with them [26]. In the field of human–computer interaction (HCI), presence is defined as the mental state where a user perceives their physical self to be present in a space that is being mediated. When immersion is increased and, in turn, distractions are reduced, focus is heightened, and users are more likely to engage with the interactive tasks at a deeper level. It has been reported that users of a VR system will often respond to virtual-world stimuli in real-world-like ways, making use of an immersive environment that significantly prompts and impacts user stimulus and response perception and behavior [13, 27].

Immersion encourages active participation in an environment where users perform tasks with a high degree of spatial awareness and control, making use of coordination and engaged bodily presence [28–30]. This again is most applicable in a procedural environment. Although a high sense of presence is achieved when a high degree of immersion is in effect, there is no guarantee that the user will undertake the task correctly, highlighting the importance of examining the extent to which immersion drives behavior.

Immersive VR environments offer users rich sensory experiences that are under their own interactive control and are realistically situated within a given context [19, 31]. In research on HCI, immersion, interactivity, and the flexibility of a system's richness are the core, fundamental aspects of design, and how they shape the way a user interacts with and experiences a system. These design aspects affect both the user's subjective perception of their engagement and the objective outcome of task performance.

2.2. Interactivity and user control

In HCI, interactivity is the extent to which users are able to change system elements and, in return, receive immediate feedback. This is a vital component of the user experience because it allows individuals to learn and discover by acting on the system [14, 32, 33]. The more interactivity there is, the more the system feels like it is a part of the user, and the more agency the user feels [34].

Within the functions of interactive VR systems, users are able to manipulate elements, make choices, and control the system. In these contexts, interactivity is essential to the performance of the task, as the learning process is based on doing and not on viewing. The facilitation of actual participation is the aspect of interactivity that is most beneficial, as this participation is the foundation of learning [6, 34, 35]. Furthermore, interaction must be suitable for the activity, within the system, and relevant in context. Interaction plays a key role in determining the ways and means users manipulate and control system elements and get instantaneous and direct feedback. In HCI, interaction is a measure of user control and user involvement. This implies that, in terms of interaction, users are allowed to partake in system operations rather than merely serve as onlookers. In interactive systems, user control and involvement are complemented by the system's exploratory capability and a sense of engagement, where the users of the system can perform tasks and view the results of their manipulations [36–39].

2.3. Realism and contextual authenticity

The concept of realism in VR denotes the degree to which the virtual world imitates the real world, including fidelity to deep appearances, control of spatial relationships, and logic of interactions. In HCI, realism, in its various forms, contributes to the attainment of ecological validity, where users are able to perceive tasks in a given context [40, 41]. Realism in virtual environments provides the user with contextual cues that guide and prompt the user toward a certain behavior, thus helping in the transfer of a user's interaction skills from the virtual environment to the real world.

Simulation research shows that a realistic environment positively influences User Engagement in task completion. It also positively influences task ambiguity and user situational awareness [42, 43]. However, realism alone, and in the absence of correct contextual clues or a strong cognitive background, may lead to incomplete or incorrectly performed tasks. This draws attention to the fact that realism should be directed to and shaped by the user's cognitive background and experiences. Realistic environments intentionally design and include contextually meaningful and behaviorally guiding elements to maximize user participation.

2.4. User engagement in immersive systems

User Engagement consists of cognitive, emotional, and behavioral components [21]. From an HCI perspective, engagement reflects a system's efficiency and describes the user-technology interaction. Flow Theory was one of the first engagement theories, considering that users become deeply involved with a task when the challenge and skill level are equally matched [44].

It is presumed that User Engagement positively influences interaction outcomes, but limited research exists evaluating the relationship User Engagement has with objective performance. It is important to note that optimal performance on a task is not indicative of a fully immersed user in the system. That being said, a fully immersed user of the system is very likely to possess and demonstrate the cognitive effort, the attention, and the persistence necessary, and that will significantly improve his/her behavioral performance.

2.5. Behavioral accuracy and interaction performance in table manners context

Behavioral accuracy is the correct completion of tasks by the user of an interactive system. It is an objective way of measuring the quality of interaction in HCI, as opposed to satisfaction and engagement, which are subjective measures. Evaluating behavioral accuracy is crucial in stepwise tasks, which require execution of sub-tasks in a certain predetermined order.

Despite its criticality, behavioral accuracy has an insignificant space in VR research, which is mostly focused on the experiential side and not the performance side. This study seeks to fill that gap by utilizing the behavioral analysis dimension in the immersive interaction assessment model, thus enhancing the understanding of the user interaction with VR systems.

In HCI, engagement can be defined as having a behavioral component, and the quality of interaction is defined by system design, while the execution of the task is defined by the interaction. Thus, it is expected that the behavioral component of system design will be mediated by the quality of interaction.

H5: User Engagement mediates the relationship between immersive VR experience (immersion, interactivity, and realism) and procedural competence, which is objectively validated through behavioral accuracy assessment.

2.6. Research gap in existing evaluation approaches

Advancing immersive learning models focuses on the role of VR in stimulating learners' cognition and learning motivation and enhancing the learning experience. Current studies analyze immersive learning in VR through presence, User Engagement, perceived usability, technology acceptance, and learning satisfaction [18, 43, 45]. Research in this area reports positive learning impacts. However, the critique of immersive learning is mostly focused on self-reported feedback, which is inherently subjective.

The most recent studies have included learning analytics and interaction logs to analyze the behavior of learners within immersive spaces. Still, behavioral traces are often analyzed in isolation or used to perform learning analytics with no integration of behavioral traces and the psychological engagement of the learners [46, 47]. This has led to an insufficient understanding of the relationship between the perceived engagement of a learner and the engagement of that learner in a given behavioral task.

This absence of integration (albeit) is a major barrier in vocational training. In most instances in this area, having a positive perception of the learning experience is of little value when the learner is unable to execute a task accurately. Engaging and immersive instructional design may lead to learners performing tasks in a sub-optimal manner, as a result of their habitual behavior and culturally driven ways of dealing with tasks. Using only subjective measures of learner engagement inflates the outcome of immersive learning frameworks when assessing workplace readiness.

2.7. Proposed integrated behavioral evaluation framework

To address this limitation, the study introduces the IBEF, which aims to concurrently assess immersive experience, User Engagement, and objective behavioral performance in relation to the Integrated Procedural Competence Model. As illustrated in Figure 1, the IBEF provides an integrated framework for evaluating VR-based immersive learning by combining subjective and objective assessment approaches. Building on this framework, Figure 2 presents the relationship between immersive experience, User Engagement, and objective behavioral performance, enabling a more comprehensive evaluation of learning processes and procedural competence in vocational training. Unlike previous immersive learning studies, the IBEF integrates subjective evaluations with objective behavioral assessments to provide a more comprehensive appraisal of VR-based immersive learning in vocational education.

2.8. Hypothesis development

H1: Immersion positively influences User Engagement.
H2: Interactivity positively influences User Engagement.
H3: Realism positively influences User Engagement.

Figure 1
Proposed Integrated Behavioral Evaluation Framework (IBEF)

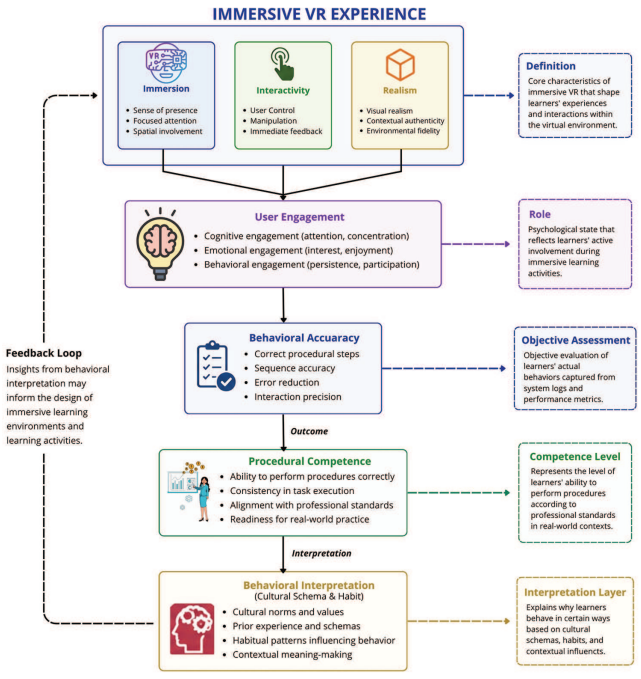
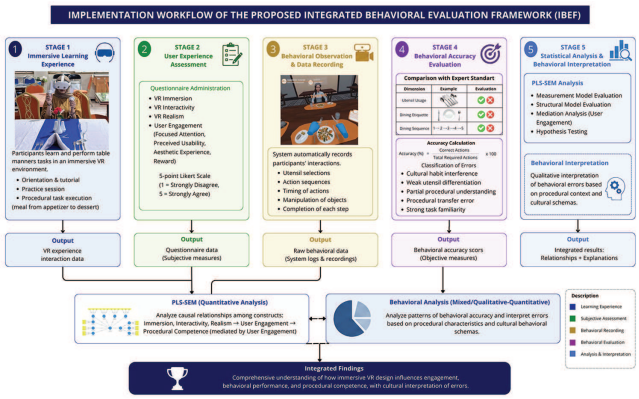


Figure 2
Implementation workflow of the proposed Integrated Behavioral Evaluation Framework



H4: User Engagement positively influences procedural competence.
H5: User Engagement mediates the relationship between immersive VR experience (immersion, interactivity, and realism) and procedural competence, which is objectively validated through behavioral accuracy assessment.

3. Method

3.1. Research design

A quantitative, explanatory research design was applied in this study [48, 49] to test the viability of the IBEF for the evaluation of procedural competence within the context of immersive vocational training. The IBEF incorporates subjective user experience and objective behavioral performance within VR to appraise the effectiveness of learning within the VR environment.

Most existing immersive learning research focuses on learner experience. In contrast, the proposed framework captures the interaction amongst design elements of an immersive system, User Engagement, behavioral performance, procedural competence, and behavioral evaluation. The explanatory research design was used to understand the VR design elements and the resulting learner behavior.

The IBEF was applied through a series of five stages. First, participants engaged in procedural learning within an immersive VR system. Second, participants' experiences of immersion, interactivity, realism, and engagement were captured via survey instruments. Third, interaction behavior was recorded. Fourth, the latent variables were examined using partial least squares structural equation modeling (PLS-SEM) [50]. Lastly, behavioral inaccuracies were assessed through qualitative analysis of the procedural context and behavioral patterns of the VR system's culture.

3.2. Participants and ethical considerations

The participants of this study were 120 undergraduate students of vocational hospitality and culinary education. The participants were selected through purposive sampling and were characterized as having a basic level of digital literacy and an absence of immersive VR experience. This sampling was intentional due to the participants being the target users of procedural VR-based learning within this study.

3.3. Proposed behavioral evaluation procedure

Through five successive evaluation stages, the integration of subjective psychological assessment with objective behavioral evaluation was made possible via the proposed IBEF.

1) Stage 1: immersive learning experience
   The participant engaged in a VR-based formal dining table manners educational session. This required the participant to don a head-mounted display and use handheld motion controllers. A formal Western dining room was created in the VR, and participants were required to complete authentic dining tasks.
2) Stage 2: user experience assessment
   Participants were asked to complete surveys that assessed the following four latent constructs: a. VR Immersion, b. VR Interactivity, c. VR Realism, and d. User Engagement.
   All measurement items were derived from the HCI literature and immersion in the formal dining task. All items were measured using a five-point Likert scale.
3) Stage 3: behavioral observation
   Participants were asked to complete the formal dining task without the presence of instructional guidance. During the task, all interactions were captured in the simulation. Behavioral performance was assessed for the following three dimensions: a. Utensil Usage, b. Dining Etiquette, and c. Dining Task Completion.
4) Stage 4: behavioral accuracy evaluation
   Behavioral accuracy was assessed by comparing participant actions to an expert-defined standard for formal dining. Incorrect behaviors were classified as one of the following: a. interference of cultural habits, b. weak utensil differentiation, c. partial understanding of the dining task, d. procedural transfer error, and e. familiarity with the dining task.
   Precision in determining behavioral accuracy was prioritized over the calculation of an accuracy percentage.
5) Stage 5: statistical and behavioral interpretation
   The final stage was the integration of subjective measurement and behavioral observation. PLS-SEM was used to analyze the relationships between characteristics of immersive systems and levels of User Engagement and procedural competence. In addition, behavioral analysis was used to determine the reasons for the procedural errors of users who were otherwise highly engaged.

3.4. Interaction environment and VR systems

An immersive VR system featuring a head-mounted display and handheld motion controllers was used. Participants interacted with elements within the virtual environment by manipulating and gesturing with objects within the system.

The system's design emphasized procedural interaction. Participants were guided through a series of interaction tasks that were governed by procedural rules. These tasks required the selection, manipulation, and arrangement of virtual elements in a prescribed order. The system offered users the ability to observe the outcomes and exercise control over their actions in response to the consequences.

The interaction environment and system design are shown in Figure 3, along with a multi-layered depiction of the interaction workflow. This includes the physical layout of the interaction system, the virtual interface, and interaction that was mediated through motion controllers. This design facilitates the real-time interaction and observation of a user's behavioral performance with respect to a task.

Figure 3
User interaction workflow in the immersive VR system, including the virtual environment, physical interaction setup, and motion-controller-based interaction



3.4. Measures

The study used both subjective and objective measures.

Subjective Constructs. The latent variables comprised 1) VR Immersion, 2) VR Interactivity, 3) VR Realism, and 4) User Engagement.

User Engagement was described as a higher-order construct and included 1) Focused Attention, 2) Perceived Usability, 3) Esthetic Experience, and 4) Reward.

Procedural Competence was described as 1) Utensil Usage, 2) Dining Etiquette, and 3) Dining Sequence.

All constructs were measured with validated scales modified from prior studies on immersive learning and HCI.

Objective Behavioral Measures

Behavioral performance was assessed as behavioral accuracy. Participants' procedural performance was measured as 1) Correct Utensil Selection, 2) Correct Dining Sequence, and 3) Correct Etiquette Execution.

Behavioral accuracy was assessed for each of the procedural tasks.

3.4. Data analysis

To evaluate the IBEF, we performed data analysis in two complementary phases. The first phase examined hypothesized relationships among latent constructs. This was done using PLS-SEM. PLS-SEM was the preferred method as it is appropriate for predictive studies with upper-order constructs, mediation, and intricate structural models [51, 52]. The assessment of the measurement model was done to verify the constructs' reliability and validity. This assessment included checking the reliability of the indicators, internal consistency, and assessment of convergent and discriminant validity. Because multicollinearity is a significant concern in SEM, it was assessed through the variance inflation factor (VIF). Once the measurement model was

validated, the assessment of the structural model was done. In this phase, the path coefficients (β), the coefficient of determination (R^2), the effect size (f^2), and the predictive relevance (Q^2) were assessed. The hypothesized relationships were evaluated for significance through bootstrapping that was run with 5,000 iterations.

The second phase built on the results of the analysis of the structural model and involved the analysis of participants' behavioral performance during immersive VR-based table manner training. This phase involved the analysis of participants' interaction behaviors during a number of simulated dining scenarios. This was done in order to capture participants' procedural performance during the training, as opposed to relying on the participants' self-reported perceptions. For each of the procedural tasks, the correct and erroneous responses were captured and summarized. From the observed procedural inaccuracies, errors were captured and assessed to recognize the repetitive behaviors that participants exhibited and at what stage participants were having challenges completing the task. This analysis was put together with the IBEF to provide further details to evaluate behavioral performance. It went beyond offering insight into procedural task completion and assessed the behavioral components that resulted in participants' procedural performance. Henceforth, the combination of structural model analysis and behavioral performance analysis offers a clear and holistic view of technology acceptance, learner engagement, and real procedural performance in immersive VR learning environments.

4. Results and Discussion

4.1. Result

4.1.1. Measurement model evaluation

The evaluation of the measurement model includes analysis of indicator reliability, internal consistency reliability, convergent validity, and discriminant validity.

All indicators exceeded the 0.70 threshold for reliability. Indicator reliability ranged between 0.852 and 0.948, and therefore, no items were removed from the model.

Internal consistency reliability is indicated by Cronbach's alphas (0.846–0.972) and composite reliability (0.907–0.975), which exceeded the threshold of 0.70.

Since the average variance extracted (AVE) ranged from 0.754 to 0.884, this indicates that convergent validity was achieved. Each construct captured more than 50% of the variance of the indicators.

Discriminant validity was also established by multiple criteria. According to Fornell–Larcker's criterion, the square root of the AVE of the constructs was greater than the inter-construct correlations. Furthermore, the Heterotrait–Monotrait Ratio (HTMT) values were all below 0.90, and the highest HTMT value was 0.732, indicating that discriminant validity was achieved. Also, in the cross-loading analysis, each indicator showed the highest loading on the intended construct.

We can also see that multicollinearity is of no concern as all the VIF values are well below the threshold of 5. All VIF values also ranged between 1.000 and 1.034.

The model fit is acceptable as the fit shows an Standardized Root Mean Square Residual (SRMR) value of 0.051.

4.1.2. Structural model evaluation

1) Coefficient of determination (R^2)

Table 1
Coefficient of determination (R^2)

Construct	R^2	Adjusted R^2
User Engagement	0.478	0.464
Interaction Performance in Table Manner Context	0.500	0.495

Table 1 shows that the R^2 value for User Engagement was 0.478, indicating that 47.8% of the variance in User Engagement is explained by VR Immersion, VR Interactivity, and VR Realism in the proposed structural model. Similarly, the R^2 value of 0.500 indicates that 50.0% of the variance in Table Manners Competence is statistically explained by the predictors included in the model. This finding indicates that the User Engagement of participants in immersive procedural learning environments is of great significance in the development of users' competence [53].

It can be concluded that the proposed model has the ability to explain User Engagement and user competence to a moderate to a great extent.

2) Effect size (f^2)

The analysis of effect sizes was conducted in order to determine the extent to which certain aspects of the constructs that comprise the structural model influenced the results of the study, as presented in Table 2. As for the degree of effects, it was found that VR Immersion had the greatest effect on User Engagement ($f^2 = 0.419$), followed by VR Realism ($f^2 = 0.323$) and VR Interactivity ($f^2 = 0.229$). This suggests that the engagement of users of immersive VR learning environments is significantly influenced by the degree of presence of the users, as well as the realism of the VR surroundings.

The f^2 value of 0.998 indicates a very large effect size for the relationship between User Engagement and Table Manners Competence, suggesting that User Engagement makes a substantial contribution to the explained variance of the endogenous construct within the structural model.

Table 2
Effect size (f^2)

Path	f^2	p-value
VR Immersion → User Engagement	0.419	0.007
VR Interactivity → User Engagement	0.229	0.025
VR Realism → User Engagement	0.323	0.024
User Engagement → Interaction Performance in Table Manner Context	0.998	0.000

3) Direct effects

Results from the structural model showed that all hypothesized direct relationships are significant, as presented in Table 3. The strongest positive relationship was that of VR Immersion with User Engagement ($\beta = 0.470$, $t = 7.503$, $p < 0.001$). This means that the more participants reported a strong sense of presence (and immersion) in the VR, the more engaged they were.

A positive relationship was also found for VR Realism with User Engagement ($\beta = 0.417$, $t = 5.521$, $p < 0.001$). This means that the more VR environments depict the real world, the more people are psychologically and emotionally engaged. The relationship

Table 3
Direct effects

Path	β	t-value	Result
VR Immersion → User Engagement	0.470	7.503	Supported
VR Interactivity → User Engagement	0.352	5.156	Supported
VR Realism → User Engagement	0.417	5.521	Supported
User Engagement → Interaction Performance in Table Manner Context	0.707	15.651	Supported

between VR Interactivity and User Engagement was also found to be significant (β = 0.352, t = 5.156, p < 0.001). This means that the more VR environments are interactive (where users can manipulate objects), the more engaged users become in the simulated environments.

Moreover, User Engagement had a positive relationship with Interaction Performance in Table Manner Context (β = 0.707, t = 15.651, p < 0.001). This implies that the more users exhibit focused attention, perceptions of user friendliness, appreciation of the esthetics, and rewards, the more accurate they are in performing the procedural dining tasks.

4.1.3. Mediation analysis

The mediating role of User Engagement in the relationships between VR experience attributes and Interaction Performance in Table Manner was examined using a bootstrapping procedure. The results indicate that User Engagement significantly mediates all three proposed relationships, as summarized in Table 4.

Among the VR experience dimensions, VR Immersion demonstrated the largest positive indirect effect on Table Manners Competence through User Engagement (β = 0.332, t = 6.520, p < 0.001). This was followed by VR Realism (β = 0.295, t = 5.313, p < 0.001) and VR Interactivity (β = 0.249, t = 4.975, p < 0.001). All indirect effects were positive and statistically significant, indicating that higher levels of immersion, realism, and interactivity were associated with higher levels of Interaction Performance in Table Manner through User Engagement.

These findings suggest that the contribution of immersive VR characteristics to Interaction Performance in Table Manner operates partly through User Engagement. In other words, the VR characteristics examined in this study are statistically associated with competence through the engagement mechanism rather than being interpreted as direct evidence of competence development. The results therefore highlight the importance of User Engagement as a mediating mechanism through which immersive VR characteristics are associated with perceived procedural competence.

4.1.4. Predictive relevance (Q2)

Predictive relevance (Q^2) is used to assess the extent to which the research model can predict the dependent variables. Hence, the Q^2 measure means to what degree the model reconstructs the observed values. A model with a high Q^2 value has a better predictive ability for the dependent variables [43]. A Q^2 value of more than 0 has predictive relevance with the following evaluation criteria: weak ($0.02 < Q^2 \leq 0.15$), moderate ($0.15 < Q^2 \leq 0.35$), and strong ($Q^2 > 0.35$). The results of the analysis are as presented in Table 5.

The model is very strongly predictive because all variables are over 0.35, most in the 0.5–0.7 range.

Table 4
Indirect effects (meditation results)

Path	β	t-value	p-value	Result
VR Immersion → User Engagement →Interaction Performance in Table Manner	0.332	6.520	< 0.001	Supported
VR Realism → User Engagement →Interaction Performance in Table Manner Context	0.295	5.313	< 0.001	Supported
VR Interactivity → User Engagement →Interaction Performance in Table Manner	0.249	4.975	< 0.001	Supported

Table 5
Predictive relevance (Q^2)

	SSO	SSE	Q^2 (= 1-SSE/SSO)
Esthetic Experience	360,000	135,782	0.623
Dining Etiquette	360,000	178,563	0.504
Dining Sequence	360,000	138,522	0.615
Focused Attention	360,000	135,385	0.624
Perceived Usability	360,000	129,122	0.641
Reward	360,000	145,571	0.596
Interaction Performance in Table Manner Context	1080,000	338,670	0.686
User Engagement	1440,000	408,526	0.716
Utensil Usage	360,000	126,413	0.649
VR Immersion	360,000	103,235	0.713
VR Interactivity	360,000	116,797	0.676
VR Realism	360,000	110,493	0.693

In detail:

1) Interaction Performance in Table Manner Context (0.686) has very high predictive capability, while User Engagement (0.716) exhibits very high predictive capability. This is to say that all of the model's main constructs are strong.
2) With VR Immersion (0.713), VR Interactivity (0.676), and VR Realism (0.693) at high relevance, the VR dimensions also keep strong explaining ability to the endogen.
3) Esthetic Experience, Focused Attention, Perceived Usability, Reward, Dining Etiquette, Dining Sequence, and Utensil Usage all have high Q2 values (> 0.5), meaning their indicators are in the model helping predictive performance.

The predictive relevance results indicate that the proposed model demonstrates adequate predictive relevance for the endogenous constructs. Furthermore, the hypothesis testing results support the proposed relationships among the research constructs. However, the generalizability of the findings should be interpreted with caution due to the limitations of the study sample.

4.1.5. Structural model visualization

This section describes the structural model that illustrates the VR system features, user-individual engagement, and Interaction Performance in Table Manner Context, as presented in Figure 4.

Using the structural model, we see how User Engagement influences Interaction Performance in Table Manner Context. This model incorporates VR features of immersion, interactivity, and realism, which are User Engagement elements. The interrelations proposed indicate the definition of User Engagement in the various immersive VR learning experiences (i.e., systems) as a mediating role. All relationships are proved to be with adequate statistical measurement.

Table 6 shows an example of how VR dining etiquette has been applied in a dining VR simulation. Overall outcomes indicate an increase in the users' competencies. However, several pieces of evidence indicated a lack of consistency in dining scenarios. The users' responses indicated an interference of schemas during the salad and bread course. The use of cutlery to consume bread in the VR simulation is a context that reflects users' personal realities and is inconsistent with Western supper course etiquette, with bread being a finger food. Behavioral engagement is inadequate to ensure users' adherence to norms, and the simulation does not compensate for the users' culturally informed procedural knowledge. VR practice should be used to minimize the cognitive dissonance of the users' procedural knowledge and enhance the simulation's context of learning.

In addition to the structural model, evidence of users' behavioral engagement is analyzed to create a fuller understanding of the execution of procedural interaction tasks of the users in the immersive VR simulation. The distribution of correct and incorrect responses during dining interactions is represented in Figure 5.

4.1.6. Comparative evaluation with state-of-the-art methods

To locate the proposed IBEF among currently available literature on immersive learning, this analysis examines the evaluation methods used in literature from 2022 to 2026. Recent immersive learning literature, as illustrated in Table 7, has focused on learner engagement, presence, and the effectiveness of instructional design.

The comparison shows that the IBEF enlarges existing models of immersive learning evaluation in three significant aspects.

First, most of the recent models focus on the evaluation of immersion, presence, and engagement of the learner. The proposed model assesses the objective accuracy of behavioral

Figure 4
Structural relationships between VR experience, User Engagement, and Interaction Performance in Table Manner Context

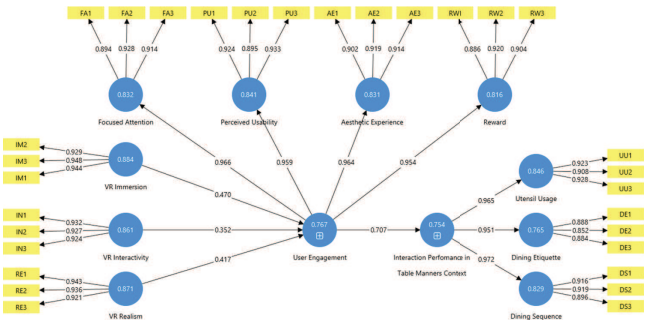


Figure 5
Correct and incorrect behavioral responses across dining interaction scenarios

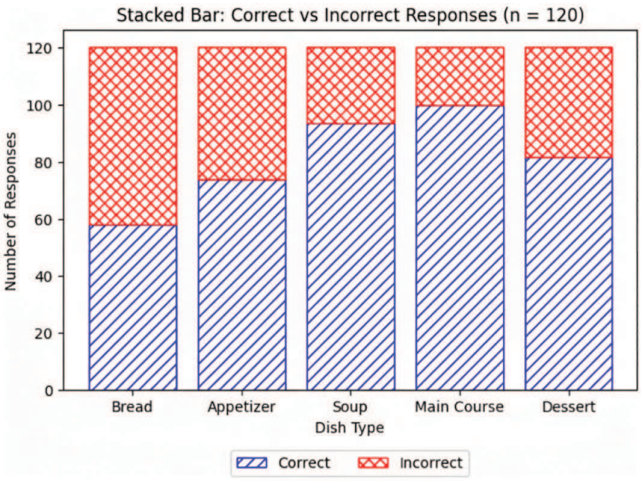


Table 6
User behavioral accuracy in utensil usage (n = 120)

Dish Type	Correct (n)	Incorrect (n)	Accuracy (%)	Common Errors Observed	Behavioral Interpretation
Bread	58	62	48.3%	Used fork and knife	Cultural habit interference
Appetize	74	46	61.7%	Used dinner fork	Weak utensil differentiation
Soup	92	28	76.7%	Used dessert spoon	Partial procedural understanding
Main Course	101	19	84.2%	Used fork only	Strong task familiarity
Dessert	81	39	67.5%	Used main fork	Transfer error

Table 7
Comparative evaluation of the proposed IBEF with recent state-of-the-art studies (2022–2026)

Study	User Engagement	Objective Behavioral Accuracy	Procedural Competence	Cultural/ Behavioral Interpretation	Integrated Evaluation Framework
[54]	Partial	✗	Partial	✗	✗
[55]	✓	✗	Partial	✗	✗
[56]	✓	Partial	✓	✗	✗
[57]	✓	✗	Partial	✗	✗
Behavioral Analysis Framework (2024)	Partial	✓	✓	Partial	Partial
Proposed IBEF (This Study)	✓	✓	✓	✓	✓

Description: ✓ = explicitly evaluated; Partial = partially addressed; ✗ = not explicitly evaluated.

actions captured during the execution of procedural tasks. This allows researchers to determine not only if learners perceive the immersive environment positively but also if learners act out the procedural tasks accurately.

Second, most of the models that evaluate learning rely on questionnaires or learning assessment tests. Unlike these models, IBEF allows researchers to evaluate the quality of interaction of learners during real VR-based procedural training by observing the participants and analyzing the procedural competency.

Third, the model offers an explanation of deviations from the desired behavioral outcomes in the case of procedural tasks. This is achieved by considering the learners' previous behavioral patterns and culturally based procedural knowledge. IBEF goes beyond the typical engagement-based models and offers a better qualitative explanation of the immersive learning outcomes.

4.1.7. Integration of PLS-SEM and behavioral performance

The PLS-SEM and behavioral analyses provide complementary evidence regarding the effectiveness of immersive VR-based table manners training. The PLS-SEM results demonstrate positive relationships between VR Immersion, VR Interactivity, VR Realism, and User Engagement, with User Engagement subsequently showing a strong positive association with Table Manners Competence ($\beta = 0.707$). These findings indicate that participants who reported higher levels of engagement also tended to report higher levels of perceived competence within the structural model.

However, the behavioral analysis provides a more differentiated picture of procedural performance. The observed accuracy varied considerably across the dining scenarios, ranging from 48.3% for bread-related interactions to 84.2% for main-course interactions. This variation indicates that positive engagement and perceived competence did not necessarily result in uniformly accurate procedural execution across all task scenarios.

The complementary nature of these findings is important for interpreting immersive learning outcomes. While the PLS-SEM results capture participants' perceptions and the structural relationships among the psychological constructs, behavioral analysis provides direct evidence of how participants performed specific procedural actions. Therefore, the two analytical approaches should not be considered redundant. Instead, they address different dimensions of learning evaluation: PLS-SEM explains the relationships among immersive experience, engagement, and perceived competence, whereas behavioral analysis identifies the extent to which procedural actions are accurately executed.

The discrepancy between the positive structural relationships and the variation in behavioral accuracy provides empirical support for the rationale underlying the IBEF. Specifically, high User Engagement should not be interpreted as sufficient evidence of accurate procedural performance. Behavioral observation is therefore necessary to identify scenario-specific procedural difficulties that may remain hidden when evaluation relies exclusively on subjective measures.

From this perspective, the behavioral findings also provide a basis for contextual interpretation. Lower accuracy in particular scenarios may reflect differences in task familiarity, prior behavioral schemas, or the complexity of procedural sequences. These interpretations should be considered contextual explanations rather than direct causal effects, because cultural schema, prior experience, and digital literacy were not directly modeled as latent variables in the present PLS-SEM analysis.

4.2. Discussion

This research builds on immersive learning studies to show that measuring learners' subjective experiences is insufficient for assessing the learning of procedures. While studies have found that immersive VR learning environments improve engagement, presence, and learning effectiveness, the assessment of learning remains primarily focused on psychological constructs to the neglect of the assessment of learning performance. In a similar vein, recent systematic reviews have described the inconsistent assessment of learning procedures in immersive learning environments and have argued for the development of more comprehensive assessment constructs that integrate pedagogy, behavior, and technology [58, 59]. To address this shortcoming, the current research introduces the IBEF, which merges the features of immersive systems, User Engagement, behavioral precision, procedural evaluation, and the behavioral assessment of interpretation. Unlike traditional behavioral evaluation methods, the IBEF incorporates the subjective experiences of learners along with the behavioral proof of learning, and offers a more integrated assessment of the learning of procedures within immersive systems. This finding reinforces the methodological rationale of the IBEF, which combines subjective structural measures with objective behavioral evidence. PLS-SEM identifies relationships among psychological and experiential constructs, whereas behavioral analysis reveals whether these perceptions are reflected in observable procedural performance. The integration of both forms of evidence therefore provides a more nuanced evaluation of immersive procedural learning than either approach alone.

The structural model indicates that immersive environments, interactivity, and realism positively affect User Engagement. This finding is consistent with recent developments in HCI literature [60, 61]. That literature argues that the immersion of learners via authentic interaction, multisensory engagement, and contextual realism advances the learning process [41, 62, 63]. HCI literature argues that immersion facilitates a learner's presence, realism fosters the manipulation of context and the generation of feedback, and realism provides contextual cues that suggest ways of clarifying procedures. These features of design support the active participation and the engaged behavior that are critical for the experiential learning process in a VR setting. These results agree with evidence that immersive VR is most beneficial when learning activities are designed around active participation and procedural practice, rather than passive learning.

While the structural model shows that User Engagement positively impacts procedural competence, the behavioral analysis highlights the subtleties of this relationship. Participants who reported high levels of engagement did not always demonstrate behavioral accuracy for all procedural tasks. As such, engagement is seen as a necessary condition for effective procedural learning, although it is not sufficient on its own. Therefore, the extent of satisfaction expressed by learners and the extent of reported engagement in immersive learning activities may lead one to believe that the learning process is effective. This belief is incorrect. These measures do not provide an adequate assessment of the extent to which learners are able to accurately perform the procedural task.

Evidence from behavior also shows that task features affect procedural accuracy. Participants showed higher accuracy levels when engaging in procedural steps that were closely structured and specified. In features that were contextually and culturally dependent such as dining scenarios, accuracy levels fell. This suggests that immersive VR is a tool that builds procedural fluency especially when task structures are clear and known; however, if task structures are unknown, cognitive burdens are required to deal with unfamiliar procedural structures along with the learned behavioral patterns. This task structure burden also reflects in VR when cognitive burdens are required to address unfamiliar task structures and real behavioral patterns.

The gap that was witnessed between engagement and acting accuracy can be explained by Schema Theory, which states that people perceive new situations and experiences through the lens of pre-existing mental frameworks. Within the context of VR dining, participants entered the virtual setting with behavioral frameworks shaped and influenced by their normal daily practices. Western dining behaviors, when placed against these frameworks, meant that participants reverted to their normal practices, despite high levels of engagement in the task. Hence, the errors that were made, in this case, stemmed from the introduction of new conflicting procedural information with the pre-existing behavioral and cognitive frameworks/schema, rather than an absence of immersive VR engagement. This is aligned with the evidence showing that procedural competence, within an immersive VR learning framework, is greatly influenced by cultural contexts.

These findings indicate that learning is both socially and culturally contextualized from a wider educational standpoint. While immersive technology can convincingly simulate genuine environments, the transfer of desirable workplace behaviors hinges on the alignment of the instructional design and the experiences of the learners. Therefore, culturally responsive instructional design needs to be embedded in immersive learning environments to address the misconception that technological realism delivers procedural skill mastery. Incorporating adaptive scaffolds, contextual prompts, and culturally responsive feedback could minimize cognitive dissonance and promote optimal behavioral transfer.

The other significant finding relates to the digital literacy of learners and its impact on immersive procedural learning [64, 65]. Even though digital literacy was not directly featured as a latent construct, behaviors suggested that the learners' confidence with digital technologies influenced the quality of their interactions in the VR environment. Those learners who possessed sounder digital skills and literacy navigated the virtual interface competently and freed their cognitive load for procedural thinking and reasoning. In contrast, learners who portrayed lesser digital skills and digital readiness then committed more cognitive load to interface manipulation and thus had less cognitive load available for procedural reasoning. What was thus demonstrated is that digital literacy is a prerequisite for meaningful engagement within immersive learning environments.

This explanation aligns with Cognitive Load Theory. Cognitive Load Theory posits that unnecessary cognitive demands placed on the user by the interface will lower the efficiency of the user's learning [46, 66, 67]. In an immersive VR environment, the learner may have to process the layout of a virtual environment, manipulate virtual objects, perceive and interpret procedural cues, and conduct an operation with their body. When the demands placed on the system by the user's operations exceed the user's capabilities, the user's cognitive resources will be split between managing the system and reasoning about the procedure, and this will lower the precision and correctness of the user's actions. The newest research also states that an immersive learning environment should reduce interaction complexity and provide flexible instructional support in accordance with the different levels of learner readiness.

From a methodological standpoint, the primary advancement this research provides is the IBEF. Recent studies have noted the severe gap in the evaluation methods of immersive learning that combine behavior analytics with learning in immersive environments because most existing methodologies looked at engagement and performance separately. IBEF attempts to address this gap and offers researchers the opportunity to establish participant engagement with immersive environments and provide insights into the prevalence of procedural mistakes, the nature of these mistakes, and their relation to cognitive and cultural dimensions. This integrated approach is a notable advancement in the evaluation of immersive learning and provides a significant extension to existing methodologies within the realm of HCI studies.

The results further develop the Technology Acceptance Model (TAM) in the context of immersive learning. Within the framework of traditional TAM [68, 69], perceived ease of use and perceived benefit are the main factors that influence the acceptance of a technology and the use of the system. In contrast, the present findings show that acceptance of the technology and high engagement do not necessarily lead to correct performance of the procedure. By adding objective behavioral data to the assessment, this study moves acceptance-oriented assessment to the evaluation of behavioral competence. It argues that the successful immersive learning experience should be measured in terms of psychological engagement, behavioral execution, and observable actions rather than acceptance of the technology.

From a practical perspective, the proposed model has important implications for educators, instructional designers, and

developers of immersive technologies. IBEF provides vocational educators with a practical evaluation approach that goes beyond learner satisfaction or engagement. Teachers can use behavioral accuracy data to identify specific procedural steps that require additional demonstration, repetition, or corrective feedback. For instructional designers, differences in behavioral accuracy across scenarios can inform the redesign of VR tasks. Scenarios with lower accuracy may require clearer visual cues, additional scaffolding, repeated practice, or more explicit procedural sequencing. For VR developers, the findings suggest that immersive quality should not be evaluated solely through engagement metrics. Interaction design should be linked to observable task performance so that system features can be evaluated according to their contribution to procedural learning. At the institutional level, IBEF can support evidence-based decisions regarding the adoption of immersive technologies by providing both experiential and performance-oriented evaluation criteria.

This study highlights the components of technological design, psychological engagement, cognitive flexibility, digital literacy, and cultural context, and how their integration influences the design and evaluation of advanced immersive learning systems. This research, by integrating these dimensions into the new IBEF, outlines a specialized method for assessing the embedded procedural skills, contextual competencies, and required behaviors of immersive learning systems. The framework specifically elevates contemporary evaluation practices of advanced learning technologies and systems by extending the emphasis from the user adoption testing phase or user acceptance to the observable behavioral performance and contextual cues this performance is based on, resulting in a robust basis for additional research and development of adaptive immersive learning systems.

5. Conclusion

This research proposed and validated the IBEF to facilitate the assessment of procedural learning within immersive VR. By incorporating behavioral accuracy and interpretative engagement along with the characteristics of immersive systems, the framework augments assessment methods that rely on learner evaluation primarily as subjective perceptions. The results suggest that interactivity, immersion, and realism stimulate User Engagement, and engagement further develops procedural competence. Nonetheless, the behavioral assessment shows that engagement does not guarantee performance of procedural behavior; therefore, objective behavioral assessment and contextual interpretation are necessary in the evaluation of immersive learning systems. This framework offers both a methodological and practical contribution by integrating PLS-SEM and behavioral analytics with advanced procedural learning to assess learning outcomes. It is also flexible for other domains outside of hospitality education in other fields of vocational and professional education with accurate procedural skill acquisition. The framework needs to be tested in different learning environments, with larger samples, and in the context of adaptive, immersive learning with artificial intelligence.

Funding Support

This work was supported by Universitas Negeri Malang through the Faculty of Engineering Decentralization Funding Program under Contract No. 20.4.119/UN32.5.2/LT/2026, for the research project entitled "Immersive Gastronomy Learning: Analisis User Experience Virtual Reality Table Manner dalam Transformasi Pendidikan Vokasional." The authors gratefully acknowledge the financial support provided by the Faculty of Engineering, Universitas Negeri Malang, which contributed to the implementation and completion of this research.

Ethical Statement

All subjects provided informed consent before participating in the study. The study was conducted in accordance with the principles of the Declaration of Helsinki and the applicable research ethics guidelines of Universitas Negeri Malang, Indonesia (No. 08.04.11/UN32.14.2.8/LT/2026).

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that support the findings of this study are openly available in the Zenodo repository at https://doi.org/10.5281/zenodo.20663266.

Author Contribution Statement

Aditia Gustiana Gunawan: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Rina Rifqie Mariana:** Conceptualization, Methodology, Validation, Formal analysis, Writing – review & editing, Supervision. **Aji Prasetya Wibawa:** Conceptualization, Methodology, Validation, Formal analysis, Writing – review & editing, Supervision. **Heru Wahyu Herwanto:** Validation, Resources, Writing – review & editing. **Moh. Muzayyin Amrulloh:** Formal analysis, Writing – review & editing, Visualization, Funding acquisition. **Dian Julianto Wahyudi:** Validation, Resources, Writing – review & editing, Funding acquisition. **Yulias Prihatmoko:** Formal analysis, Writing – review & editing, Visualization, Funding acquisition.

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How to Cite: Gunawan, A. G., Mariana, R. R., Wibawa, A. P., Herwanto, H. W., Amrulloh, M. M., Wahyudi, D. J., & Prihatmoko, Y. (2026). Bridging Engagement and Behavioral Performance in Immersive Virtual Reality: The Role of Interaction Design and Cultural Context. *Artificial Intelligence and Applications*. https://doi.org/10.47852/bonviewAIA620210834