Development and Psychometric Validation of the Interactive Communication Scale for Digital Learning Environments (ICDLES)

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***Abstract*—Despite the global proliferation of e-learning platforms, the Arab educational context lacks a culturally validated instrument to assess the multidimensional nature of digital interaction. This study addresses this critical gap by constructing and developing the Interactive Communication Scale for Digital Learning Environments (ICDLES) the first psychometrically validated tool of its kind designed specifically for the Arab educational context. A set of rigorous statistical analyses yielded a solid factorial model with six critical elements representing the core of interactive communication within the digital environment: Learner–Content Interaction (LCI), Learner–Instructor Interaction (LII), Learner–Learner Interaction (LLI), Learner–System Interaction (LSI), Social–Emotional Interaction (SEI), and Metacognitive Interaction (MI). Exploratory and confirmatory factor analyses confirmed the scale had solid construct validity and high reliability, with sufficient internal consistency across all items and dimensions. The scale development employed a scale development and validation study design using Exploratory Factor Analysis (EFA) to identify and refine the factor structure, Confirmatory Factor Analysis (CFA) to verify the stability of the six-dimensional model, and Rasch model analysis to ensure objective linear measurement and item-level fit. The scale's six-dimensional structure reflects unique sociocultural and institutional characteristics of Saudi Arabian digital learning contexts, filling a critical gap in the Arab educational literature. The study suggests using the scale as a diagnostic and developmental tool to facilitate the redesign of digital learning environments, foster interactive pedagogy, and achieve lasting improvement in online learning quality. Implications are specifically tied to the six-factor structure, providing targeted guidance for each dimension of interactive communication.**

***Keywords*—e-learning, interactive communication, digital learning environments, educational interaction, interactive communication scale, psychometric properties, digital learning quality**

I. Introduction

The last few years have involved considerable changes in the forms of teaching and learning. Interactive digital environments have become one of the integral elements of modern educational systems. The latest communication technologies, electronic learning management systems and pedagogical communication tools have strengthened Interactive Communication as the core element of the educational process in digital environments and have proven the quality and success of digital education [1–3].

Contemporary technologies have also redefined the reciprocal relationships between the educator, the learner, and the learning materials. Education is no longer a one-way process of imparting knowledge. Rather, it is a two-way interactive and collaborative process characterized by dialogue, real-time interaction and experience sharing across various digital communication tools [3]. The ability to cultivate productive communication among learners, the content, the instructor, and the electronic system is one of the most significant factors contributing to the quality and effectiveness of e-learning [4, 5].

In his foundational Theory on Patterns of Interaction in Distance Education, Moore [1] categorized educational interaction into three types: learner–content, learner–instructor, and learner–learner. Subsequent scholars added a fourth interaction dimension—system/interface (more recently called learner–interface) which has become even more relevant in smart and open learning environments [6, 7]. More recent frameworks have further expanded this typology to include socio-emotional and metacognitive dimensions that capture the affective and self-regulatory aspects of digital learning [8, 9].

Recent studies indicate that positive interactive communication contributes to enhancing academic achievement, increasing educational satisfaction, and fostering motivation for self-directed learning, in addition to being a key factor in building digital learning communities that encourage dialogue and creativity [8, 10]. Garrison, Anderson, and Archer [11] also emphasize in the Community of Inquiry model that interaction forms one of the three pillars of teaching presence, alongside social and cognitive presence, as it enables learners to collaboratively construct knowledge within an interactive and safe digital environment.

While Western-centric instruments have dominated the field, they often fail to capture the unique sociocultural dynamics of collectivist Arab educational environments. Despite what global literature emphasizes about the crucial role of interactive communication in the success of e-learning, the tools to measure it remain limited and often lack proper cultural and psychometric adaptation for the Arab context. Most measures used have been developed in Western educational settings with varying educational and cultural characteristics [12, 13]. Additionally, many measurement tools have focused on only one dimension of communication such as learner–instructor interaction—without addressing the other dimensions comprehensively: learner–content, learner–learner, learner–interface, socio-emotional, and metacognitive interaction [14, 15]. This gap is particularly pronounced in Saudi Arabian and broader Arab higher education contexts,

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where the rapid expansion of e-learning platforms during and after the COVID-19 pandemic has not been accompanied by equivalent growth in culturally sensitive measurement tools [16, 17].

The Arab world presents a distinctive and underexplored context for digital learning research. Arab higher education institutions have undergone accelerated digitalization, with Saudi Arabia alone enrolling over 1.9 million students in higher education [18]. Culturally, Arab learners operate within a predominantly collectivist social framework that shapes collaborative and instructor-led interaction preferences in ways that Western-normed scales may not adequately capture. Furthermore, the Arabic linguistic and cultural context introduces unique considerations around social presence, hierarchical learner-instructor relationships, and gender-segregated learning environments none of which are addressed by existing interaction scales developed and validated primarily in Western contexts [19].

Educational literature has shown that interactive communication is a qualitative indicator of the quality of the e-learning environment and is closely associated with academic achievement, satisfaction, digital belonging, and trust in the e-system [5, 20]. Therefore, developing a standardized scale to measure interactive communication has become a scientific and practical necessity to ensure the quality of digital learning experiences and to guide institutional improvement efforts in this field.

Based on these data, the current study aims to construct and develop a scale of interactive communication in digital learning environments and to verify its psychometric properties (validity and reliability), based on established theoretical frameworks such as the Community of Inquiry (CoI) model and the Interaction Theory in e-learning, with the goal of providing a reliable standardized tool to help researchers and educational policymakers assess the quality of educational communication in digital environments.

Though technology in digital learning environments is advancing rapidly, how to use technology in these environments to facilitate communication among participants is still being researched. A number of recent studies, however, indicate that, despite their potential, interactive communication in e-learning environments is often ineffective, lacking in depth, and misaligned with the educational goals in the majority of learning establishments [13, 17, 21]. The absence of strong, interactive communication bogs educational literature down in describing a lack of engagement, the presence of apathy, and social disconnection, all of which stultify learning outcomes, and which diminish the educational experience [4, 7]. Recent studies also show that the tools used to assess levels of communication in computer-mediated environments often lack construct validity and reliability and often fail to account for context [14, 22].

In addition, prior research has concentrated on particular dimensions of interaction, such as the learner's interaction with the teacher or with the content, neglecting the other three dimensions of the integrated framework for interactive communication in e-learning: learner-content interaction, learner-instructor interaction, learner-learner interaction, and learner-interface interaction. These dimensions capture the essence of interactive communication and illustrate a digital learning environment in which a learner interacts cognitively and socially while gaining the learning motivation and satisfaction [3, 11].

Despite the research consensus on the importance of these dimensions in supporting the quality of e-learning, studies still lack a standardized and comprehensive scale with established psychometric properties (validity – reliability – practical applicability). This deficiency in measurement tools limits the ability to realistically assess the level of interaction in digital environments and weakens the capacity of educational decision-makers to develop effective strategies for improving communication in e-learning. Based on the above, the study's problem lies in the need to develop and standardize an Arabic scale for interactive communication in digital learning environments and to verify its psychometric properties (validity and reliability) in a way that reflects the specificity of the cultural context and contributes to supporting the quality of digital learning and developing its educational practices. Accordingly, the study problem can be formulated in the following questions:

(1) What are the theoretical dimensions and main components that form the concept of interactive communication in digital learning environments in light of recent educational literature?
(2) What is the proposed perception for developing and constructing Interactive Communication in Digital Learning Environments scale (ICDLES)?
(3) What are the psychometric properties (validity and reliability) of the Interactive Communication in Digital Learning Environments scale (ICDLES)?

A. *Significance of Study*

The need for development of adequately operationalized and scientifically based technological tools that assess the degree of interactive communications in the e-learning environments continues to remain critical due to the importance of measuring the effectiveness and quality of the electronic learning processes. The already in progress instructional paradigm shift towards e-learning has resulted in an apparent void in the literature regarding measuring the interaction behaviors of the various e-learning stakeholders. This offers an opportunity for the development of this study, which attempts to make a pioneering contribution to literature by creating a new instrument that is anchored in current validated international theories, notably the Theory of Interaction in Distance Education [1] and the Community of Inquiry Model [11].

The study's main theoretical contribution is the integration of the four dimensions of interactive communication in e-learning (learner–content, learner–instructor, learner–learners, learner–system) into one conceptual framework for the first time. This is done through the lens of recent studies in digital communication, intrinsic motivation, and learner-centered pedagogy. The study also adds to the literature a harmonized construct and a measuring tool to assist researchers in analyzing the impact of interactive communication on e-learning, education, and learning satisfaction.

The study's main practical contribution is equipping educational and training organizations with a dependable evaluative framework to measure the effectiveness of interactivity in digital learning, to enhance e-learning environment design, and to inform actionable strategies in education and technology. Moreover, the study lays the groundwork for future studies on the influence of interactive communication on motivation, digital confidence, and academic achievement, thereby contributing to the continued improvement of the quality of e-learning.

II. Literature Review

A critical analysis of recent literature underscores the multidimensional nature of interactive communication in Digital Learning Environments (DLEs) as a primary determinant of pedagogical efficacy [1, 23]. Global research consistently Identifies Learner–Content Interaction (LCI), Learner–Instructor Interaction (LII), Learner–Learner Interaction (LLI), and Learner–System Interaction (LSI) interactions as the pillars of student success. For instance, Kuo *et al*. [5] and Al-Subaiy [16] both identified LCI as the strongest predictor of satisfaction, while Borup *et al*. [24] demonstrated that these relationships are not merely transactional but provide essential socio-emotional support. Furthermore, Martin *et al*. [2] emphasized that modern interaction frameworks must expand to include "Metacognitive Interaction", a dimension often neglected by traditional measurement tools but vital for deep understanding and self-regulation.

The transformative potential of digital integration is further evidenced in North African contexts, where empirical research highlights a direct link between technology-enhanced environments and student achievement. Oumelaid *et al*. [25] conducted a comprehensive experimental study to analyze the impact of digital classrooms on mathematics calculation skills and learner motivation. Their findings revealed significant improvements in both mathematical performance and motivation within the experimental group compared to a control group receiving traditional instruction. While these results underscore the ability of innovative instructional methodologies to optimize outcomes, the study like many in the region focuses primarily on academic performance and generalized motivation. This highlights a persistent gap in the literature: while we can observe that digital tools improve performance, we currently lack a multidimensionally validated instrument, such as the ICDLES, to measure the specific patterns of interactive communication—be they technical, social, or cognitive that catalyze these improvements.

Despite this theoretical consensus, a significant measurement gap persists within the Arab educational landscape. While researchers like Al-Fraihat *et al*. [14] and Hrastinski [26] argue that interaction must be evaluated in depth to prevent learner disengagement, regional studies reveal a persistent failure in current digital implementations. Al-Shammari [12] documented that interaction levels in Gulf universities remain below desired thresholds, particularly regarding collaborative LLI. This deficit is not merely pedagogical but methodological; as Shehab *et al*. [22] and Al-Subaiy [16] argue, existing scales predominantly developed in Western contexts—lack the cultural and linguistic calibration necessary to accurately assess the collectivist social frameworks and hierarchical instructor-student relationships inherent in the Arab world.

To address this "cultural-measurement gap," recent regional scholarship has begun to establish rigorous psychometric precedents. AlAli and Saleh [19] and Saleh and AlAli [27] have demonstrated the success of using advanced analytical techniques such as the Rasch model and Confirmatory Factor Analysis (CFA) to validate scales for distance-learning self-efficacy and technical confidence within Saudi Arabian contexts. However, a comprehensive instrument specifically dedicated to the full spectrum of interactive communication has remained absent. By synthesizing the methodological rigor of AlAli and Saleh with the expanded conceptual dimensions (Socio-Emotional and Metacognitive) proposed by Martin *et al*. [8], the current study constructs the Interactive Communication Scale for Digital Learning Environments (ICDLES). This scale represents the first psychometrically sound, culturally grounded tool designed to inform digital education policy and practice specifically within the Arab higher education setting.

A. Theoretical Framework

E-learning is highly responsive to developing paradigms of educational communication. Communication with, and among, educators is no longer a uni-directional, informational exchange and has evolved to a multi-dimensional, relational, and integrated cognitive, social, and technology-driving phenomenon. A number of studies indicate that relational, interactive communication is a primary predictor of the effectiveness and quality of e-learning [8, 23]. In the digital world, relational-communicative interaction is an ongoing, holistic process that facilitates meaning construction, knowledge transfer, and the motivational and cognitive engagement of learners [1, 11]. Therefore, there is an urgent need, both practically and theoretically, to ascertain the level of relational-communicative interaction within e-learning environments in order to assess the educational impact of such environments.

Interactive communication involves a set of processes in an e-learning system focused on active learning and learning adaptability [28]. This definition encompasses more than basic interactions. It takes into consideration the cognitive, affective, and social dimensions critical for constructive learning and the formation of learning communities through digital technologies [11, 23].

Rather than representing a disparate catalogue of theories, the conceptual framework underlying the ICDLES is built as a coherent, layered architecture in which each theoretical tradition directly maps onto one or more of the scale's dimensions. This integrated framework proceeds from foundational typological theory through social constructivism to self-regulatory and technological acceptance models, as described below.

At the foundational level, Moore's [1] Interaction Theory in distance education establishes the primary typology of educational communication: learner–content, learner–instructor, and learner–learner interaction. This typology, while foundational, is insufficient in isolation for capturing the full complexity of digital learning, which prompted subsequent expansions of the model. Moore [1] explained that increased interaction between the learning components boosts the level of understanding, satisfaction, and achievement.

Building on this foundation, Garrison, Anderson & Archer's [11] Community of Inquiry (CoI) model consisting of cognitive, social, and teaching presences provides the relational architecture that connects individual interactions to the co-construction of knowledge. Interactive communication is the essential mechanism that integrates these three presences. The CoI framework directly informs the LCI, LII, and LLI dimensions of the ICDLES by articulating how cognitive engagement, instructor facilitation, and peer discourse collectively constitute the learning experience in digital environments.

The Social Constructivism model of Vygotsky [29] posits that knowledge is created through the interactions and collaboration of learners, making interaction a principal component of active e-learning. Crucially, Vygotsky's theory grounds the Social–Emotional Interaction (SEI) dimension of the ICDLES: within the Zone of Proximal Development, learning is mediated not only by cognitive scaffolding but by the emotional safety and supportive relational environment created through digital communication. Thus, the social construction of emotional safety learners' sense of belonging, psychological security, and affective engagement is theoretically anchored in Vygotskian constructivism and operationalized through the SEI dimension.

Zimmerman's [30] model of self-regulated learning provides the theoretical grounding for the Metacognitive Interaction (MI) dimension. Zimmerman conceptualizes self-regulation as a cyclical process of forethought, performance, and self-reflection, in which learners monitor and adjust their cognitive strategies in response to feedback from the learning environment. In digital settings, this self-regulatory process is enacted through metacognitive interaction—the learner's deliberate awareness, monitoring, and control of their own learning processes within the digital environment. Thus, Zimmerman's framework directly justifies the inclusion of the MI dimension as a theoretically grounded construct that extends beyond mere cognition to encompass deliberate self-regulation in e-learning.

Finally, the Technology Acceptance Model [31] and Information Processing Theory [32] provide the theoretical underpinning for the Learner–System Interaction (LSI) dimension. TAM's constructs of Perceived Ease of Use (PEOU) and Perceived Usefulness (PU) directly correspond to the LSI items measuring interface functionality, system reliability, and the learner's trust in and engagement with the e-learning platform. Attention and understanding of content are further enhanced when there is prompt feedback and active communication through a well-designed interface, as posited by Information Processing Theory. Taken together, these theoretical frameworks provide a unified, multi-layered conceptual architecture that ensures the ICDLES has both breadth and depth in its measurement of interactive communication dimensions.

Research suggests that interactive communication is one of the key elements of quality in e-learning. The more the elements of the education system interact, the greater the satisfaction, achievement, motivation, and continuity in learning [8, 14]. Bernard *et al*. [9] further demonstrated this in their meta-analysis of 70 studies. Means *et al*. [33] confirmed that positive interaction between learners and content and instructors is reflected in academic performance, and that learning environments with high levels of interactivity are more likely to outperform traditional environments in achievement and satisfaction. Hrastinski [3] argues that interactive communication is the core of 'social presence,' which facilitates the necessary human and cognitive interaction in the digital space.

The existing scale has been designed through the fusion of these theoretical frameworks to offer a psychometric tool designed to measure thoroughly the dimensions of interactive communication in e-learning. The scale encompasses six major dimensions pertaining to the different types of interactions of the learners with components of the virtual environment. This measure is expected to contribute to revealing the strengths and weaknesses in the design of e-courses, and to identifying the relationships between interactive communication and indicators of learning quality, such as achievement, satisfaction, motivation, and confidence in the e-system [3, 8, 14].

Based on educational literature and previous studies [1, 3, 8, 28], six main dimensions of the interactive communication concept proposed in this study can be identified, as follows:

(1) Learner–Content Interaction (LCI): This dimension shows the relationship between the learner and the digital learning materials and how the materials are able to encourage self-learning and critical thinking. In their studies, Bernard *et al*. [9] and Martin *et al*. [8] show that positive learner–content interaction has a strong correlation with better academic results and a higher level of learning satisfaction.

(2) Learner–Instructor Interaction (LII): This is the educational communication that occurs between the student and the online instructor using the different available mediums (forums, chats, feedback). Martin *et al*. [8] and Kuo *et al*. [5] pointed out that students' satisfaction levels were positively impacted by the frequency and quality of instructor–learner interaction.

(3) Learner–Learner Interaction (LLI): This shows the degree of collaboration and sharing of knowledge among peers in the online environment. Alzahrani [34] states that positive social interaction fostered the sense of belonging and enhanced collaborative thinking among peers.

(4) Learner–System Interaction (LSI): The Learner-System Interaction (LSI) dimension draws theoretical grounding from Davis's [31] Technology Acceptance Model (TAM). TAM posits that technology adoption and effective use are primarily determined by two perceptual constructs: Perceived Ease of Use (PEOU) the degree to which a user believes using a system requires minimal effort and Perceived Usefulness (PU) the degree to which a user believes the system will enhance their performance. In the ICDLES, LSI items directly operationalize both TAM constructs: items addressing platform navigation and technical interface ease reflect PEOU like "I find the digital learning platform easy to navigate", while items addressing the system's support for learning goals reflect PU like "The learning management system effectively supports my academic

tasks". This explicit TAM-LSI linkage grounds the Learner-System dimension in an empirically robust theoretical framework with extensive prior validation in educational technology research [35].

(5) Socio-Emotional Interaction (SEI): This dimension represents the human connections that arise in the virtual environment through participation, support, and a sense of belonging. Grounded in Vygotsky's [29] social constructivism, this dimension captures the social construction of emotional safety—the extent to which learners feel psychologically secure, emotionally supported, and socially included in the digital learning space. Studies by Garrison *et al*. [11] and Hrastinski [3] have shown that this dimension is essential for building a stimulating and safe learning environment. Research has further demonstrated that socio-emotional interaction is positively associated with affective learning outcomes [37].

(6) Metacognitive Interaction (MI): This is the learner's awareness of their learning processes and their monitoring of their own performance within the digital environment. Directly grounded in Zimmerman's [30] self-regulated learning theory, this dimension operationalizes the self-regulatory cycle of forethought, monitoring, and self-reflection within digital contexts. Metacognitive interaction reflects the learner's deliberate awareness, strategic planning, and adaptive control of their cognitive processes in e-learning, which promotes academic success and long-term learning autonomy.

Table 1 presents these dimensions along with their operational definitions and the elements or indicators derived from them, which will later be used as the basis for formulating the items of the final scale.

Table 1. Dimensions of the interactive communication scale in digital learning environments

Main Dimension	Concept	Items / Indicators Associated with the Dimension
Learner–Content Interaction (LCI)	This refers to the extent to which the learner actively engages with the instructional content on the digital platform through reading, analysis, application, and self-reflection.	Planning learning steps in advance and selecting appropriate strategies. Monitoring performance during digital activities and adjusting approaches when needed. Continuously evaluating one's understanding of the content. Using higher-order thinking strategies while processing information. Identifying and correcting errors independently during online learning.
Learner–Instructor Interaction (LII)	This demonstrates the constructive relationship the learner and the instructor build in an online learning environment, which includes academic guidance, verbal communication, and response feedback.	Regular communication with the instructor through virtual lectures or discussion forums. Receiving timely feedback and corrections. Clarity of instructions and availability of academic support. Encouragement from the instructor to participate and engage in dialogue. Feeling respected and valued by the instructor.
Learner–Learner Interaction (LLI)	This refers to Mutual communication among learners within the digital environment, fostering social and cognitive collaboration and strengthening the sense of learning community.	Collaborating in group activities and digital projects. Participating in forums and virtual discussion rooms. Exchanging knowledge and experiences with peers. Offering assistance and feedback to others. Feeling a sense of belonging to an integrated digital learning community.
Learner–System Interaction (LSI)	This dimension describes the learner's relationship with the digital learning system at a technical and institutional level. It describes the learner's interaction with the system's interface and tools, as well as the level of organizational/technical support the institution provides. It captures the technical system's quality, ease of system use, and the efficiency of the institution's support services.	Ease of using the platform interface. Clarity of page design and digital tools. System responsiveness to various commands. Smooth navigation across learning modules. Sense of comfort while using the digital system. Participation in institution-led activities. Access to technical and administrative support when needed. Confidence in the fairness of online academic procedures. Perception of transparency in digital rules and policies. Feeling of belonging to the digital learning institution.
Social–Emotional Interaction (SEI)	These are experienced by the learner in the virtual setting, the learner's emotional and social interaction, and communications, as they relate to the exchange of feelings, empathy, and psychosocial protective factors, including, sense of emotional, social, and cognitive, safety and social, and psychological together with motivation and learning overall.	Expressing emotions and personal experiences within the digital learning environment. Feeling psychologically safe when interacting with others. Building positive relationships with peers and instructors through the platform. Receiving emotional support or encouragement from peers or the instructor. Developing a sense of social connectedness and belonging within the digital community.
Metacognitive Interaction (MI)	The learner's ability to engage with their own thinking processes through planning, monitoring, and self-evaluation, which supports deep learning and enhances academic performance in digital environments.	Planning learning steps in advance and selecting appropriate strategies. Monitoring performance during digital activities and adjusting approaches when needed. Continuously evaluating one's understanding of the content. Using higher-order thinking strategies while processing information. Identifying and correcting errors independently during online learning.

III. Materials and Methods

A. Research Design

This study employed a scale development and validation study design to construct and psychometrically validate the Interactive Communication in Digital Learning Environments Scale (ICDLES). This design is appropriate when the primary objective is the construction and standardization of a new psychometric instrument, as it entails systematic domain specification, item generation, expert content validation, pilot testing, and multi-method construct validation [38]. This approach enables rigorous examination of the scale's factorial structure and confirms the instrument's validity and reliability across multiple statistical frameworks.

For this purpose, a comprehensive instrument, the

Interactive Communication in Digital Learning Environments Scale (ICDLES) was created. ICDLES is a comprehensive construct designed to assess six factors: Learner–Content Interaction (LCI), Learner–Instructor Interaction (LII), Learner–Learner Interaction (LLI), Learner–System Interaction (LSI), Social–Emotional Interaction (SEI), and Metacognitive Interaction (MI). The scale development procedure began after receiving ethical clearance from the King Faisal University Institutional Review Board. The scale was first used in a pilot study to test for clarity, reliability, and validity, and was then administered to the primary study sample. The collected sample data were analyzed, and the findings were subjected to descriptive and inferential statistical analysis.

B. Population and Sampling

The focus of this research was undergraduate students from all Saudi Arabian universities during the 2024/2025 academic year. A sampling frame was constructed to encompass all the universities from the five divided regions of Saudi Arabia: North, South, East, West, and Central, to achieve spatial balance.

From the total sampling frame, 850 students were randomly selected. The sample size was determined based on a subject-to-item ratio of 17:1 [39, 40]; with 50 scale items, a minimum sample of 850 participants is recommended to ensure adequate statistical power for exploratory and confirmatory factor analyses. This ratio falls within the recommended range for reliable factor analysis results and is consistent with best practices in scale development research. The Interactive Communication in Digital Learning Environments Scale (ICDLES) was administered, and data were collected via a Google Form. To increase the range and rate of responses, the questionnaire was sent to participants through several channels, including official university email accounts and WhatsApp.

It should be noted that the reliance on WhatsApp as one of the distribution channels may have introduced selection bias toward students with higher digital access and greater familiarity with digital communication platforms. This limitation is discussed further in the Limitations section.

For the sake of easier processing, the university managements were contacted, and a letter of ethics clearance was provided. University managements also provided the recruited facilitators like academic peers with a copy of the response tickets and instructions to keep the response tickets.

C. Interactive Communication in Digital Learning Environments Scale (ICDLES)

A review of the literature was conducted to start the process of constructing the Interactive Communication in Digital Learning Environments Scale (ICDLES) and understand the primary indicators which comprise the functions of communication in digital learning. The review process identified six areas of focus: Learner–Content Interaction (LCI), Learner–Instructor Interaction (LII), Learner–Learner Interaction (LLI), Learner–System Interaction (LSI), Social–Emotional Interaction (SEI), and Metacognitive Interaction (MI). The multi-dimensional nature of the learners' communication within the realms of the digital learning environment and the comprehensive nature of the construct, created considerations for each dimension and the functional creation of a thorough item set for that dimension.

The process of validation for the scale occurred in a number of steps. The scale was first presented to a panel of eleven experts in Saudi universities. The researcher modified the questions based on the feedback and suggestions of the experts, as well as the alternate solutions they proposed. Therefore, the scale was revised. A pilot study was then conducted with 120 undergraduate students in order to assess the scale's validity and reliability. The responses generated in this pilot study and the qualitative feedback that accompanied them were analyzed and used for the scale's revision. The evaluation of construct validity was done primarily with the Rasch model. This psychometric model provides a unique, objective linear approach, which is why it is used for this kind of validation in psychological and educational contexts [41].

The internal validity and structural integrity of the ICDLES were evaluated using Rasch measurement, a probabilistic model that assesses how well observed data fits theoretical expectations. The primary focus of this analysis is the evaluation of model-data fit, which relies on Infit and Outfit statistics. These statistics measure the consistency of response patterns to ensure the scale is functioning reliably. Specifically, Infit (information-weighted fit) refers to the weighted fit of an item or person; it is sensitive to unexpected responses near an item's difficulty level (for example, a student with high interactive ability missing a relatively easy item). Outfit (outlier-sensitive fit) is more sensitive to "outliers" unexpected responses far from the item's or person's location on the latent trait continuum. Practically, these are expressed as Mean Square (MNSQ) values, where a value of 1.0 indicates a perfect fit between the data and the model. Following the established guideline of 0.4 to 1.5 MNSQ, along with standardized fit statistics (Zstd) between −2.0 and +2.0, three items were identified as "misfitting". These items showed excessive "noise" or inconsistency, suggesting they did not align well with the overall construct of interactive communication. Consequently, one item was removed from the Metacognitive Interaction (MI) dimension and two items were omitted from the Learner–Learner Interaction (LLI) dimension. This refinement process ensures that the final version of the ICDLES remains a precise and mathematically sound instrument for measuring the intended latent traits within the Arab higher education context.

To ensure that each item in the ICDLES functions as intended, we evaluated item polarity using the Point-Measure Correlation (PTMEA-CORR). This statistic is a critical diagnostic tool used to determine if an individual item's direction aligns with the overall latent construct (interactive communication) being measured. In practical terms, a positive correlation indicates that the item is "working well" within the scale; it signifies that respondents who possess a higher level of the latent trait (e.g., strong metacognitive skills) are indeed scoring higher on that specific item. Conversely, a negative point-measure correlation represents a "worst-case scenario" in scale development, suggesting that the item is counterproductive or may be measuring the opposite of what was intended. Such items typically require deletion or significant modification to protect the unidimensionality or the singular focus of the scale. Following the methodological standards established by AlAli and Saleh [19], a correlation range of 0.2 to 1.0 is considered evidence of a productive and valid measurement. In this analysis, all items demonstrated positive correlations consistently within this recommended range, confirming that every item in the final scale contributes effectively to the assessment of interactive digital communication. (A detailed list of these correlations is provided in Table A1).

In Rasch analysis, ensuring the unidimensionality of a scale is essential; this confirms that the instrument is measuring one specific, primary trait per dimension rather than a mixture of unrelated factors. To assess this, we analyzed the distribution of variance. Specifically, the raw variance explained by measures indicates how much of the data's behavior is accounted for by the intended construct, which should ideally exceed 40%. Complementary to this, the first contrast of unexplained variance which identifies any potential "secondary" noise or sub-traits should remain at or below 15%. The ICDLES demonstrated a raw variance of 51.4% and a first contrast of unexplained variance of only 5.2%. These results indicate that the scale possesses a strong, singular focus, statistically confirming its fit to the Rasch model's requirements for unidimensionality (see Table A2).

Calibration and Rating Scale Functioning: Rudder's analysis demonstrated how calibration can validate the functioning of a polytomous rating scale. This advanced interval level analysis reviews if the 1 to 5 response categories are used consistently and logically. To determine rating seed calibration and scale functionality, the ICDLES was used. This is summarized in Table A3 and the category probability curve (Fig. A1) The analysis in these appendices describes the responsive and rating categories calibration ordering tiers analysis "sustained". In Table A3, the observed probable response frequency to rating distributed categories suggested tiered rating probabilities for tiered response frequencies. The most frequently observed tier of the rating scale was 3, for which 51 respondents (34%) chose. The next most frequent rating was rank 4, with 41 (27%) respondents. Scale 5 was chosen 29 times (19%) and the least frequently chosen tier was rank 2, which was selected 21 times (14%). The scale with the least responses was scale 1, for which 9 (6%) respondents. The observed distribution of responses demonstrated consistent progression and is enough evidence that respondents were able to distinguish each level in the rating scale. Stepwise evolution is further evidence that each level in the construct was distinguished and the rating scale functioned as intended.

In Rasch measurement, the values of items and persons separation indices become essential indicators of the instrument's capacity to reliably distinguish respondents based on the latent trait. This means that for every respondent and/or instrument no duplicates should arise. Generally, along with an aligned continuum of difficulty (as the items become passed or failed), spacing out items leads to a better estimation of ability levels for respondents. When the items' difficulty levels become disconnected or poorly aligned, a spacing out items' continuum becomes ineffective and no distinct measurement estimates become created. In this case, the measurement becomes less useful. A 49-item ICDLES was measured for separation and reliability with a sample of 120 students. To the best of Rasch measurement practices, minimum benchmarks of acceptability were defined as a reliability of 0.50 and a separation index of 2.00 [19]. As illustrated in Table A4, the results were impressive. The person separation index of 4.08 with a reliability of 0.88 indicated that the system was very active at differentiating between levels of respondent ability, and the index of 3.07 on the item separation with a reliability of 0.79 reiterated that the items were sufficiently spread in difficulty levels. All values meet or exceed the recommended criteria, confirming the scale's strong psychometric properties.

D. Data Analysis

To answer the research question and analyze the psychometric properties, the construct validity was established, and complete psychometric evaluation was done. This included the evaluation of the reliability which was measured using McDonald's Omega and Composite Reliability, and convergent and discriminant validity.

To further examine the measurement properties, the Rasch model was implemented using Winsteps software. This method was chosen because it can provide estimates for each person's ability and for each item's characteristics, including difficulty and discrimination. The model also produces person and item reliability estimates, which gauge the accuracy of these estimates [40].

The authors studied the validity of the factor by using a stepwise method that incorporates both Exploratory Factor Analysis and Confirmatory Factor Analysis, using SPSS and Amos, respectively. The author utilized CFA, a type of Structural Equation Modeling (SEM), to analyze the said factor structure that the author hypothesized from the EFA and from the theory. This technique helps to ascertain the relationships between the latent constructs, confirm the dimensionality of the instrument, and validate the factor loading, which is important for establishing construct validity of the instrument [41].

IV. RESULT

What are the procedures for developing an Interactive Communication in Digital Learning Environments Scale (ICDLES) and verifying the psychometric properties in Saudi environments?

There are steps to developing an Interactive Communication in Digital Learning Environments Scale (ICDLES). The construct validity of the scale was verified using different methods.

A. Indicators and Coefficients of Construct Validity

To evaluate the internal consistency of the ICDLES, MacDonald's omega (ω) and Composite Reliability (CR) were employed. These indices provide more robust estimates of reliability than the traditional Cronbach's alpha by capturing the degree to which items within each dimension consistently measure the same underlying construct, without assuming equal factor loadings. As reported in Table 2, MacDonald's omega values ranged from 0.749 to 0.867, while CR values ranged from 0.727 to 0.857. All coefficients significantly exceed the commonly accepted threshold of 0.70, indicating satisfaction with high levels of internal consistency across all six dimensions. Substantively, these results suggest that the items are highly cohesive and that the scale will produce stable, repeatable results when administered to Arab higher education students.

Construct validity was further supported through the examination of convergent and discriminant validity. Convergent validity was assessed using the Average Variance Extracted (AVE), which reflects the proportion of variance in the observed variables accounted for by the latent construct. AVE values ranged between 0.558 and 0.682 which are above the threshold of 0.50, confirming the presence of convergent validity. To assess discriminant validity the comparison was made between the square root of the AVE (√AVE) for each construct and the inter-construct correlations. Table 2 shows that the (√AVE) of all dimensions was greater than the correlations, which demonstrates that the construct is unique and measures a different level of interactive communication. These results prove the scale is reliable and has convergent and discriminant validity [41].

Table 2. Indicators and coefficients of construct validity

Constructs	Items	Macdonalds Omega	CR	AVE	$\sqrt{AVE}$
Learner–Content Interaction	8	0.799	0.778	0.574	0.758
Learner–Instructor Interaction	8	0.777	0.761	0.595	0.771
Learner–Learner Interaction	6	0.749	0.727	0.558	0.747
Learner–System Interaction	8	0.867	0.857	0.682	0.826
Social–Emotional Interaction	8	0.863	0.848	0.680	0.824
Metacognitive Interaction	8	0.861	0.842	0.677	0.823

B. Construct Validity According to the Rasch Model

Rasch model analysis was used to ascertain the construct validity of the scale. This model employs the most objective analysis of any measurement in psychology and education. Moving beyond Classical Test Theory, the Rasch model was utilized to evaluate the fundamental measurement properties of the scale. Specifically, it was used to assess item difficulty, person ability, and the overall "fit" of the items, ensuring that the five-point Likert scale functioned consistently across the entire continuum of the latent trait. Data collected was analyzed through the Rasch Model for validity and reliability. To test the final E-learning Confidence Scale's validity and reliability, the following was completed:

The scale's validity was calculated and assessed via the MNSQ values for the infit, and the results indicated that the scale was valid to a reasonable degree. Scale validity scores according to MNSQ values fall within the safe limits, which should lie between 0.4 and 1.5. It is consistent with the item polarity analysis according to PTMEA values, whose value should be between 0.2 and 1. It has a suitable standardized fit statistic (Zstd) value, which should be between −2 and 2, as shown in Table 3 below.

Table 3. Item fit analysis for interactive communication in digital learning environments scale

Items	Measure	Infit		Outfit		Pt-measure	
		MNSQ	ZSTD	MNSQ	ZSTD	CORR	EXP
MI4	0.17	1.82	1.8	1.89	1.8	0.59	0.57
SEI6	0.13	1.74	1.8	1.86	1.7	0.58	0.67
MI8	0.31	1.63	0.7	1.77	1.5	0.68	0.68
MI7	0.01	1.54	1.6	0.97	0.8	0.66	0.72
MI5	0.16	1.46	1.8	1.76	1.4	0.65	0.67
SEI7	0.44	1.41	1.5	1.58	1.7	0.58	0.64
SEI5	0.18	1.39	0.9	0.91	1.5	0.54	0.63
MI1	0.41	1.41	0.8	0.97	0.9	0.66	0.66
SEI4	0.34	1.31	1.1	0.89	0.7	0.55	0.62
MI2	0.60	1.20	−1.5	1.45	−0.8	0.64	0.67
LCI8	0.35	0.97	−0.8	1.02	−0.9	0.65	0.66
MI3	0.79	0.70	0.3	1.11	0.5	0.72	0.69
LVI7	0.17	1.12	0.6	0.86	−1.5	0.65	0.67
MI6	0.22	1.12	0.8	1.14	−1.4	0.67	0.65
SEI8	0.24	0.09	0.6	1.06	−1.1	0.67	0.65
LSI5	0.34	1.07	−0.6	0.82	1.2	0.67	0.63
LLI6	0.27	1.04	−0.7	1.36	−0.4	0.64	0.65
SEI3	0.15	0.99	1.1	0.69	1.6	0.68	0.72
LCI6	0.13	1.02	1.2	0.71	1.2	0.68	0.69
LCI5	0.06	0.92	−1.2	0.63	−1.8	0.72	0.68
LLI1	0.28	0.63	−1.7	0.77	−1.4	0.73	0.70
LSI7	0.37	0.73	−1.5	0.72	−1.7	0.74	0.64
SEI2	0.26	0.81	0.3	1.23	0.7	0.67	0.64
LCI3	0.34	0.87	0.1	0.93	1.0	0.67	0.64
LIN6	0.27	0.91	0.6	0.79	1.7	0.71	0.64
LII1	0.15	0.99	0.7	0.81	0.1	0.65	0.63
LSI8	0.11	0.95	0.2	0.99	−1.1	0.62	0.68
LCI1	0.35	0.87	0.3	1.49	0.6	0.63	0.67
SEI1	0.35	0.91	0.6	0.91	−1.2	0.68	0.67
LLI3	0.26	0.87	0.4	1.00	0.7	0.67	0.68
LLI5	0.27	0.94	0.3	0.85	−0.5	0.65	0.66
LCI4	0.62	0.97	0.9	1.05	0.6	0.65	0.69
LII3	0.57	0.93	1.2	0.83	1.2	0.68	0.64
LSI4	0.26	0.83	0.3	0.85	1.2	0.72	0.67
LII2	0.18	0.85	0.5	0.87	−1.1	0.66	0.68
LSI3	0.45	0.97	−1.3	0.74	−1.4	0.68	0.64
LII8	0.24	0.93	−1.5	0.66	−0.7	0.68	0.69
LLI4	0.35	0.87	0.7	0.85	−0.3	0.68	0.67
LSI2	0.45	0.78	−0.4	0.91	−1.6	0.70	0.66
LLI2	0.26	1.03	0.6	0.89	−1.6	0.71	0.68
LLI5	0.42	0.87	1.8	0.73	1.4	0.71	0.67
LII4	0.40	0.78	0.7	1.32	−1.6	0.70	0.73
LCI2	0.12	0.92	−1.1	0.91	−0.5	0.70	0.61
LII7	0.13	0.94	−1.2	0.67	−1.6	0.71	0.65
LII6	0.42	0.73	−1.3	0.87	−1.3	0.74	0.67
LSI1	0.51	0.89	−1.6	0.95	−0.9	0.76	0.65

Table 4. Item dimensionality of Interactive Communication in Digital Learning Environments Scale (ICDLES)

Variance Source	Empirical			Modeled
Total raw variance in observations	60.2	100%		100%
Raw variance explained by measures	49.3	43.6%		43.7%
Raw variance explained by persons	14.5	16.4%		16.4%
Raw Variance explained by items	10.1	19.8%		19.6%
Raw unexplained variance (total)	46.0	59.4%	100%	59.3%
Unexplained variance in 1st contrast	9.3	12.4%	16.2%	
Unexplained variance in 2nd contrast	8.3	13.7%	18.1%	
Unexplained variance in 3rd contrast	5.3	8.9%	11.6%	
Unexplained variance in 4th contrast	4.3	7.2%	9.4%	
Unexplained variance in 5th contrast	2.8	4.6%	6.0%	

The findings also demonstrate compatibility with calibration measurement analysis. Specifically, the dimensionality results are consistent with Rasch model expectations, as the proportion of raw variance explained by the measures exceeds 40%, while the unexplained variance in the first contrast remains below 15. These indicators confirm the adequacy of the data's dimensional structure and support the appropriateness of the measurement model, as summarized in Table 4.

The Rasch model outlines two types of reliability: person reliability and item reliability. Each focus on a different aspect of the measurement's reliability. The cutoff for reliability is typically set at 0.50, while the person and item separation index should be above 2 to be considered as having enough discrimination power [19, 41]. For this study, these guidelines were used to evaluate the reliability of the scale. The results indicate that both person and item reliability were satisfactory, thus, establishing that the scale was reliable. This is further illustrated in Table 5.

Table 5. Person and item separation and reliability for Interactive Communication in Digital Learning Environments Scale (ICDLES)

Measurement Statistics	Score	Count	Measure	Error	Infit		Outfit	
					IMSQ	ZSTD	IMSQ	ZSTD
Mean	163.3	46.0	0.72	0.18	1.03	−0.4	1.04	−0.3
S.D	29.4	0.0	1.09	0.04	0.60	2.8	0.56	1.6
Real rmse	0.21							
Adj. sd	1.02							
Separation	4.37							
Person reliability	0.90							
Mean	183.0	850.0	0.00	0.12	1.00	0.00	1.05	0.1
S.D	23.1	0.0	0.31	0.02	0.17	1.2	0.52	1.4
Real rmse	0.18							
Adj. sd	0.29							
Separation	2.46							
Item reliability	0.85							

C. Construct Validity through Factor Analysis

The construct validity of the scale was assessed using factor analysis in two consecutive steps. First, an Exploratory Factor Analysis (EFA) was performed to delineate the factors, and a Confirmatory Factor Analysis (CFA) was subsequently conducted to evaluate the measurement model. EFA was conducted in SPSS and CFA was performed in AMOS.

1) Exploratory Factor Analysis (EFA)

This was employed during the initial phase of scale development to identify the underlying factor structure of the item pool. It allowed us to determine the essential dimensions of Interactive Communication and eliminate items that did not contribute significantly to the construct's conceptual framework. Using Principal Components Analysis with oblique Promax rotation, an Exploratory Factor Analysis was conducted on the 50-item scale, as the factors were expected to correlate. Factors were retained if their eigenvalue was greater than one. The extracted factors, their structural components, and factor loadings are presented in Table 6.

Table 6. The results of the exploratory factor analysis using Promax method

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
Learner–Content Interaction	3.412	48.739	48.739
Learner–Instructor Interaction	1.623	23.193	71.931
Learner–Learner Interaction	1.097	15.666	87.597
Learner–System Interaction	0.450	6.424	94.021
Social–Emotional Interaction	0.231	3.298	97.319
Metacognitive Interaction	0.135	1.927	99.246

The Principal Components Analysis (PCA) results, detailed in Table 6, show the extraction of six components corresponding to different types of interactions in a learning environment. The most prominent one, Learner Content Interaction, received the highest ranking, with an eigenvalue of 3.412 and 48.739% of the overall variance. The second most prominent one, Learner Instructor Interaction, had an eigenvalue of 1.623, explained an additional 23.193% of the overall variance, for an overall cumulative variance of 71.931%. The third one, Learner Learner Interaction, had an eigenvalue of 1.097, accounting for 15.666% of the variance, bringing the cumulative total variance to 87.597%.

The rest of the components, Learner System Interaction (eigenvalue of 0.450, 6.424%), Social Emotional Interaction (eigenvalue of 0.231, 3.298%), and Metacognitive Interaction (eigenvalue of 0.135, 1.927%), also account for very small portions of explained variance, for a total cumulative variance of 99.246% examining with respect to the proposed theoretical framework. During the refinement of the scale, we reviewed the factor loadings by Exploratory Factor Analysis for each dimension (in Table 7) and based on established psychometric standards, items only maintained those with salient loadings (≥0.40) on their respective dimensions.

Table 7 presents the results of the Exploratory Factor Analysis. Each scale item exhibited clear and consistent loading patterns, and the scale items were loaded on the factor they were intended. Each factor loading exceeded the minimum threshold of 0.40, demonstrating strong alignment between the items and the respective factors and reinforcing the six interaction dimensions. There were no concerning cross-loadings which means that the scale was able to keep its original structure with no item deletions. Therefore, the final scale consisted of 50 items across the six dimensions: Learner–Content Interaction (8), Learner–Instructor Interaction (8), Learner–Learner Interaction (6), Learner-System Interaction (8), Social-Emotional Interaction (8), and Metacognitive Interaction (8). These findings confirm the scale's factorial validity and structural reliability.

Table 7. Loading factors of the scale items on their dimensions in the exploratory factor analysis

		Loading					
Construct	Items	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Learner–Content Interaction	LCI1		0.873				
	LCI2		0.731				
	LCI3		0.833				
	LCI4		0.850				
	LCI5		0.768				
	LCI6		0.842				
	LCI7		0.886				
	LCI8		0.844				

Learner–Instructor Interaction	LII1					0.858	
	LII2					0.700	
	LII3					0.686	
	LII4					0.899	
	LII5					0.779	
	LII6					0.773	
	LII7					0.540	
	LII8					0.684	
Learner–Learner Interaction	LLI1	0.691					
	LLI2	0.915					
	LLI3	0.936					
	LLI4	0.711					
	LLI5	0.807					
	LLI6	0.663					
Learner–System Interaction	LSI1				0.691		
	LSI2				0.860		
	LSI3				0.810		
	LSI4				0.828		
	LSI5				0.810		
	LSI6				0.810		
	LSI7				0.662		
	LSI8				0.733		
Social–Emotional Interaction	SEI1						0.702
	SEI2						0.840
	SEI3						0.770
	SEI4						0.602
	SEI5						0.711
	SEI6						0.628
	SEI7						0.736
	SEI8						0.849
Metacognitive Interaction.	MI1			0.708			
	MI2			0.536			
	MI3			0.725			
	MI4			0.585			
	MI5			0.630			
	MI6			0.825			
	MI7			0.811			
	MI8			0.814			

2) *Confirmatory Factor Analysis (CFA)*

Once the structure was established via EFA, CFA was conducted on a separate sample to verify the model's fit. This confirmed the construct validity, ensuring that the empirical data statistically supported the theoretically proposed multi-dimensional structure of the scale. Confirmatory Factor Analysis (CFA) was used to assess the factorial construct validity of the finalized 50-item scale. For this type of analysis, the measurement model to be tested is one where the items are specified to load onto six different latent dimensions, as illustrated in Fig. 1.

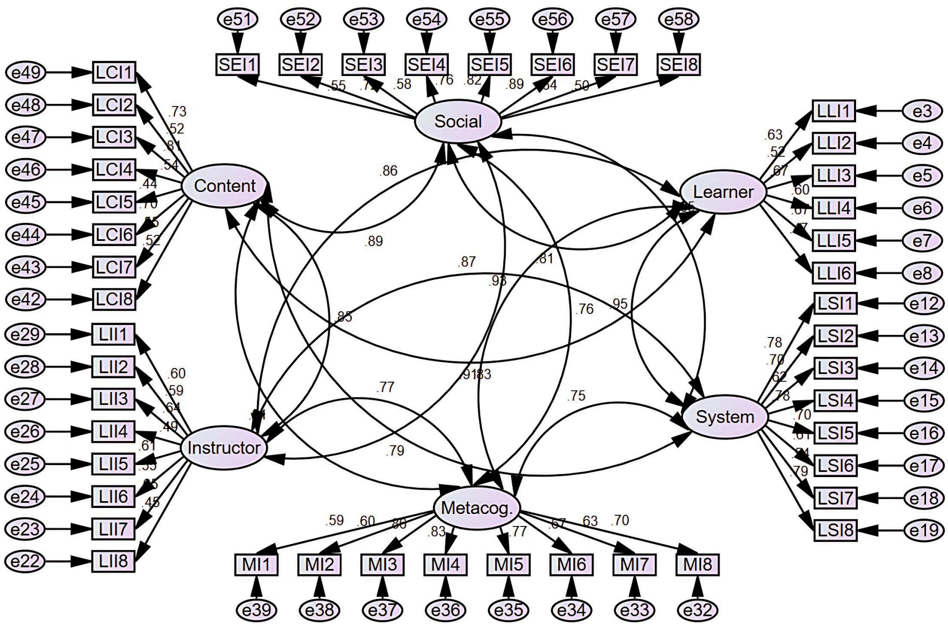

Fig. 1. Confirmatory factor analysis results illustrating the relationships between the scale items and their corresponding latent dimensions.

Results of the Confirmatory Factor Analysis (CFA) validate the predicted factor structure of the scale. As shown in Fig. 1, every item has substantial factor loadings on the assigned latent dimensions. The correlation among the six dimensions was both positive and strong, representing a measurement structure that is both unified and consistent with the theory.

To evaluate the internal construct validity, the values of the model fit indices in Table 8 are reviewed. The indices state that the measurement model is good, thus affirming that the relationship between the scale items and the latent dimensions is accurate and sufficiently defined. These results collectively point out that the measurement model achieves the standards of goodness of fit and that the model offers a sufficiently consistent, psychometrically robust structure.

Table 8. Results of the confirmatory factor analysis for the measurement model relating scale items to their latent dimensions

Name of category	Indicators of the internal construct validity	Level of acceptance	Indexes in the proposed model
Absolute fit	ChiSq	$P > 0.05$	Significant
	RMSE	RMSE < 0.08	0.069
Incremental fit	CFI	CFI > 0.90	0.934
	TLI	TLI > 0.90	0.925
	NFI	NFI > 0.90	0.937
Parsimonious fit	Chisq/df	Chis/df < 5.0	Chisq/df = 3.28 < 5.0

V. Discussion

The development and psychometric validation of the Interactive Communication Scale for Digital Learning Environments (ICDLES) represent a significant contribution to the Arab educational literature. The results of the exploratory factor analysis revealed a cohesive and well-defined six-dimensional factorial model: Learner–Content Interaction (LCI), Learner–Instructor Interaction (LII), Learner–Learner Interaction (LLI), Learner–System Interaction (LSI), Social–Emotional Interaction (SEI), and Metacognitive Interaction (MI). Critically, this structure is not merely an empirical finding but reflects a theoretically grounded architecture that maps directly onto the integrated conceptual framework described in this study.

The emergence of six rather than three or four dimensions can be theoretically explained by the expanded theoretical architecture of the ICDLES framework. Moore's [1] three-type typology provides the foundational LCI, LII, and LLI dimensions, but the addition of LSI, SEI, and MI reflects the evolution of e-learning theory toward more holistic models of digital interaction. Specifically, the CoI framework's emphasis on social and teaching presence predicts that peer and instructor interactions would emerge as distinguishable dimensions; Vygotsky's social constructivism grounds the independent emergence of the SEI dimension as the mediating affective-relational context within which knowledge is co-constructed; and Zimmerman's self-regulation model predicts the distinctiveness of metacognitive interaction as a self-directed, reflective process that operates independently of social and content-based interactions. The LSI dimension's independence is consistent with TAM's proposition that perceived ease of use and perceived usefulness are foundational antecedents of all subsequent learning behaviors in digital environments [31].

The factor structure demonstrated strong internal reliability and alignment with the established theoretical models of e-learning, particularly the Community of Inquiry Model and the Technology Acceptance Model [5, 39]. Such alignment strengthens the construct validity of the scale and situates it within the current theoretical and empirical literature. Notably, the high loadings of the LSI items on a separate factor validate TAM's central propositions within the Arab e-learning context, confirming that system usability and interface quality are perceived as distinct from, and foundational to, other interaction types.

The establishment of the scale was done in accordance with the precepts of scale development science. After determining the purpose of the scale and the components of the associated theoretical framework, and after conducting a thorough review of the literature, scale items were developed, reviewed by a twelve-member expert panel (CVI = 0.83–1.00; S-CVI = 0.92), and refined through pilot testing. The multi-stage validation approach ensures that the ICDLES meets the highest standards of psychometric rigor.

The psychometric analyses confirmed that the scale demonstrates sufficient validity and reliability. The discriminant validity results—indicating that each construct addresses a different facet of the interactive communication construct with no overlap—are particularly noteworthy, as they confirm that the six dimensions are theoretically and empirically distinguishable rather than merely arbitrary subdivisions of a single global construct. This finding aligns with theoretical arguments that interactive communication in e-learning is genuinely multidimensional [8, 23]. The reliability coefficients reported by McDonald's Omega and composite reliability, well above the established levels in the psychological and educational research fields, further support the consistency of the scale.

The Rasch model analysis confirmed the coherence of the items and the strength of their representation of the latent construct of interactive communication. The strong Learner–Content Interaction (LCI) factor—explaining 48.7% of the total variance—reflects the predominant content-centric nature of current Saudi e-learning platforms, wherein access to and engagement with digital materials constitutes the primary mode of student interaction with the learning environment. This finding is consistent with Al-Shammari's [12] observation that learner–content interaction is the most developed dimension of interactive communication in Gulf university e-courses, while socio-emotional and metacognitive dimensions remain comparatively underdeveloped. The person separation index further demonstrated the ability of the scale to capture varied levels of interactive communication of learners.

The CFA results were highly supportive of the proposed six-factor model. The model fit indices confirmed that the proposed dimensions were successfully aligned with the theoretical model, validating both the structural integrity and construct validity of the scale. The clarity of scale items and the sequential, expert-validated construction process contributed to the strong fit, ensuring that items accurately represented their respective dimensions without ambiguity.

The results indicate multiple facets of interactive communication beyond the technical, encompassing human, cognitive, and institutional aspects. Interaction with the electronic system was identified as the primary interaction type upon which all other interaction types depend, given that it provides content access and channels communication with educators and fellow learners. This finding reinforces TAM's proposition that the foundational layer of perceived system utility and ease of use must be established before higher-order social and cognitive interactions can flourish [14, 31]. Communication with educators was essential for improving learner motivation and engagement, while communication with fellow learners was important for the creation of a nurturing social learning environment that supports cooperative and constructive thinking.

From a theoretical perspective, the scale fills an important gap by providing a more sophisticated tool that captures interactive communication in its technical, social, cognitive, and organizational dimensions, as opposed to earlier one-dimensional measures. The ICDLES thus provides a significant contribution to efforts to assess and enhance the quality of e-learning programs, especially in the context of the Arab world where no culturally validated equivalent has previously existed.

The study's findings also imply that enhancing the constructive feedback element within digital education interactive communication frameworks requires an integrated approach that encompasses more than the provision of new technologies, and includes supportive technical infrastructure, ongoing teacher training, and the adoption of interaction-focused instructional design practices that foster multiple channels of communication.

VI. Conclusion and Limitations

In light of the study's objective to construct and develop a scale for interactive communication within digital learning environments, it can be concluded that the results have yielded a robust psychometric instrument characterized by high levels of validity and reliability. This tool can measure the construct through a comprehensive and integrated approach. Statistical analysis included Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Rasch modeling demonstrated that the scale possesses a stable factor structure comprising six primary dimensions. These dimensions encapsulate the essence of interactive communication in digital settings, aligning with contemporary theoretical frameworks in e-learning.

The findings further reveal that interactive communication is not a unidimensional construct; rather, it is a multidimensional latent variable where cognitive, social, technical, emotional, and metacognitive interactions intersect, reflecting the complex nature of learning in digital environments. Notably, interaction with the system emerged as the fundamental basis upon which other interaction patterns are built. Simultaneously, interaction with instructors and peers plays a pivotal role in enhancing motivation and fostering a supportive interactive learning community, which contributes to the development of critical thinking and collaborative learning.

The scientific significance of this study lies in providing a standardized Arabic scale that addresses a distinct gap in the educational literature. By offering a reliable normative tool to assess the quality of interactive communication in e-learning, this study supports ongoing evaluation and continuous improvement of digital learning environments. Furthermore, the scale serves as a practical framework for academic research, pedagogical application, quality assurance systems, and data-driven educational decision-making.

Consequently, the adoption and implementation of this scale across diverse educational contexts are expected to improve the design of e-courses, enhance interactive teaching practices, and elevate the quality of the digital learning experience in a sustainable manner. This alignment is consistent with the requirements of digital transformation in education and the vision for the future of pedagogy.

Several limitations of the current study should be acknowledged. First, the sample was drawn exclusively from Saudi Arabian universities during the 2024/2025 academic year, which limits the generalizability of the findings. Further studies are needed to confirm the scale's applicability outside the Saudi context, particularly in other Arab countries and in diverse cultural, linguistic, and institutional settings. The cultural specificity of the Arab educational context including norms of collectivism, instructor authority, and gender-segregated learning environments may limit the direct transferability of the scale's factor structure to Western or other non-Arab contexts.

Second, the reliance on WhatsApp as one of the distribution channels for data collection may have introduced selection bias toward students with higher digital access and greater familiarity with digital communication platforms. Students who are less digitally connected or who use the platform less frequently may be underrepresented in the sample, potentially inflating estimates of positive digital interaction.

Third, the use of EFA and CFA on the same sample may have inflated model fit indices. While this is a common practice in initial scale development studies, independent validation samples are recommended in future research to provide unbiased confirmation of the factor structure.

Fourth, the scale is based on self-report data, which are inherently subject to social desirability bias and may not fully capture actual interactive communication behaviors in digital learning environments. Future studies using behavioral trace data from LMS analytics would complement and validate the self-report findings.

VII. Recommendations and Future Research Directions

On the basis of the results of the current study concerning the development and validation of the Interactive Communication Scale for digital learning environments, a number of actionable recommendations and future research directions focused on the improvement of instructional communication in online contexts and the facilitated effective digital pedagogy.

A. Practical Recommendations

The six-dimensional structure of the ICDLES carries distinct practical implications grounded in the study's empirical results:

(1) Learner–Content Interaction (LCI): As this dimension explained the largest portion of the variance (48.7%), it suggests that curriculum designers must prioritize high-fidelity, interactive content as the primary driver of engagement rather than a secondary resource.
(2) Learner–System Interaction (LSI): The foundational role of LSI implies that institutional investment in accessible and stable technological infrastructure is a prerequisite for the success of any subsequent pedagogical innovation.
(3) Socio-Emotional Interaction (SEI): Given the significance of this dimension in our model, instructors are encouraged to intentionally design virtual affective spaces—such as synchronous check-ins and peer-support forums—to mitigate the risks of digital isolation.
(4) Metacognitive Interaction (MI): The validation of this dimension highlights the need for e-learning platforms to integrate self-monitoring tools, such as learning dashboards, to operationalize Zimmerman's self-regulation cycle.
(5) Learner–Instructor (LII) and Learner–Learner (LLI) Interaction: The distinct clustering of these dimensions underscores the necessity for structured collaborative activities and diverse feedback channels to sustain the dialogic nature of the digital classroom.

B. *Future Research Directions*

To ensure the scale's psychometric properties remain stable, its generalizability should be determined by applying it to more extensive and varied samples at different levels of education—including general and higher education—as well as different cultures and learning environments. Future studies with independent samples are particularly recommended to replicate the CFA findings and confirm the structural validity of the scale.

To determine the predictive role of digital learning quality, the next step should be to analyze the potential correlational and causal relationships between interactive communication and academic achievement, learning motivation, e-confidence, and student satisfaction.

Following advancements in educational technology, more focused and/or shorter versions of the scale might be developed to evaluate interactive communication in particular educational settings such as mobile learning or virtual reality environments.

1) The application of cutting-edge analytics and AI methodologies may assist in monitoring and associating learners' interactive communication behavior across various digital environments and assessing them in relation to outcome achievement, helping to formulate predictive models that enhance instructional design.
2) Studies examining differences in levels of interactive communication between traditional and digital learning environments and their effects on the quality of the learning experience may contribute to the formulation of more cohesive hybrid education frameworks.

APPENDIX

Table A1. Item fit analysis for Interactive Communication in Digital Learning Environments Scale (ICDLES)

Items	Measure	Infit		Outfit		Pt-measure	
		MNSQ	ZSTD	MNSQ	ZSTD	CORR	EXP
LLI6	0.06	2.19	3.40	2.45	6.9	0.55	0.69
LLI1	−0.11	2.28	2.9	3.25	4.3	0.56	0.64
MI4	0.06	1.67	1.6	1.77	1.6	0.55	0.69
MI9	0.17	1.82	1.8	1.89	1.8	0.59	0.57
SEI6	0.13	1.74	1.8	1.86	1.7	0.58	0.67
MI8	0.31	1.63	0.7	1.77	1.5	0.68	0.68
MI7	0.01	1.54	1.6	0.97	0.8	0.66	0.72
MI5	0.16	1.46	1.8	1.76	1.4	0.65	0.67
SEI7	0.44	1.41	1.5	1.58	1.7	0.58	0.64
SEI5	0.18	1.39	0.9	0.91	1.5	0.54	0.63
MI1	0.41	1.41	0.8	0.97	0.9	0.66	0.66
SEI4	0.34	1.31	1.1	0.89	0.7	0.55	0.62
MI2	0.60	1.20	−1.5	1.45	−0.8	0.64	0.67
LCI8	0.35	0.97	−0.8	1.02	−0.9	0.65	0.66
MI3	0.79	0.70	0.3	1.11	0.5	0.72	0.69
LVI7	0.17	1.12	0.6	0.86	−1.5	0.65	0.67
MI6	0.22	1.12	0.8	1.14	−1.4	0.67	0.65
SEI8	0.24	0.09	0.6	1.06	−1.1	0.67	0.65
LSI5	0.34	1.07	−0.6	0.82	1.2	0.67	0.63
LLI7	0.27	1.04	−0.7	1.36	−0.4	0.64	0.65
SEI3	0.15	0.99	1.1	0.69	1.6	0.68	0.72
LCI6	0.13	1.02	1.2	0.71	1.2	0.68	0.69
LCI5	0.06	0.92	−1.2	0.63	−1.8	0.72	0.68
LLI8	0.28	0.63	−1.7	0.77	−1.4	0.73	0.70
LSI7	0.37	0.73	−1.5	0.72	−1.7	0.74	0.64
SEI2	0.26	0.81	0.3	1.23	0.7	0.67	0.64
LCI3	0.34	0.87	0.1	0.93	1.0	0.67	0.64
LIN6	0.27	0.91	0.6	0.79	1.7	0.71	0.64
LII1	0.15	0.99	0.7	0.81	0.1	0.65	0.63
LSI8	0.11	0.95	0.2	0.99	−1.1	0.62	0.68
LCI1	0.35	0.87	0.3	1.49	0.6	0.63	0.67
SEI1	0.35	0.91	0.6	0.91	−1.2	0.68	0.67
LLI3	0.26	0.87	0.4	1.00	0.7	0.67	0.68
LLI5	0.27	0.94	0.3	0.85	−0.5	0.65	0.66
LCI4	0.62	0.97	0.9	1.05	0.6	0.65	0.69
LII3	0.57	0.93	1.2	0.83	1.2	0.68	0.64
LSI4	0.26	0.83	0.3	0.85	1.2	0.72	0.67
LII2	0.18	0.85	0.5	0.87	−1.1	0.66	0.68

LSI3	0.45	0.97	−1.3	0.74	−1.4	0.68	0.64
LII8	0.24	0.93	−1.5	0.66	−0.7	0.68	0.69
LLI4	0.35	0.87	0.7	0.85	−0.3	0.68	0.67
LSI2	0.45	0.78	−0.4	0.91	−1.6	0.70	0.66
LLI2	0.26	1.03	0.6	0.89	−1.6	0.71	0.68
LLI5	0.42	0.87	1.8	0.73	1.4	0.71	0.67
LII4	0.40	0.78	0.7	1.32	−1.6	0.70	0.73
LCI2	0.12	0.92	−1.1	0.91	−0.5	0.70	0.61
LII7	0.13	0.94	−1.2	0.67	−1.6	0.71	0.65
LII6	0.42	0.73	−1.3	0.87	−1.3	0.74	0.67
LSI1	0.51	0.89	−1.6	0.95	−0.9	0.76	0.65

Table A2. Item dimensionality of Interactive Communication in Digital Learning Environments Scale (ICDLES)

Variance Source	Empirical			Modeled
Total raw variance in observations	93.2	100%		100%
Raw variance explained by measures	53.4	51.4%		51.3%
Raw variance explained by persons	26.3	27.6%		26.7%
Raw Variance explained by items	21.6	23.6%		21.7%
Raw unexplained variance (total)	50.0	48.6%	100%	47.1%
Unexplained variance in 1st contrast	5.1	5.2%	11.0%	
Unexplained variance in 2nd contrast	5.1	5.1%	10.0%	
Unexplained variance in 3rd contrast	3.7	3.6%	7.9%	
Unexplained variance in 4th contrast	3.7	3.6%	7.7%	
Unexplained variance in 5th contrast	3.3	3.3%	6.3%	

Table A3. Calibration scaling analysis of Interactive Communication in Digital Learning Environments Scale (ICDLES)

Category Lable	Observed Count %	Observed Average	Sample Expect	Infit MNSQ	Outfit MNSQ	Structure Calibration	Category Measure
1	9(6%)	1.79	0.02	1.83	1.93	None	(−2.25)
2	21(14%)	−0.35	0.17	1.38	1.34	−2.30	−0.86
3	51(34%)	0.26	0.34	1.04	1.17	−0.38	0.16
4	41(27%)	1.45	0.55	0.67	0.63	1.05	0.84
5	29(19%)	1.32	0.94	1.27	1.26	1.64	2.90

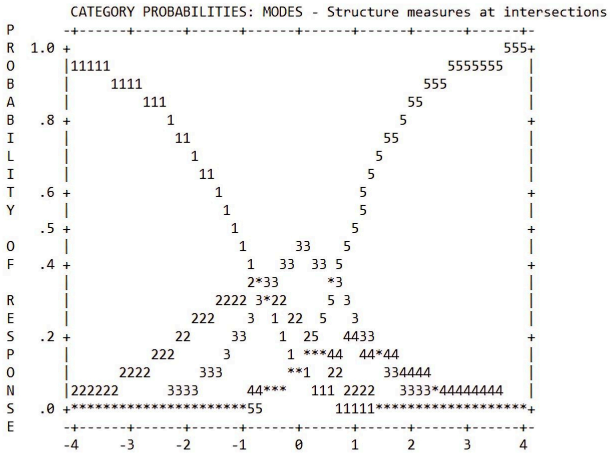

Fig. A1. The summary of the category structure of Level of ICDLES.

Table A4. Person and Item separation and reliability for (ICDLES)

Measurement Statistics	Score	Count	Measure	Error	Infit		Outfit	
					MNSQ	ZSTD	MNSQ	ZSTD
Mean	122.1	50.0	0.80	0.21	1.06	−0.4	1.13	−0.4
S.D	37.6	0.0	1.31	0.05	0.63	3.4	0.70	3.4
Real rmse	0.18							
Adj. sd	1.14							
Separation	4.08							
Person reliability	0.88							
Mean	171.3	150.0	0.02	0.21	1.00	0.0	1.10	0.1
S.D	7.8	0.0	0.33	0.01	0.21	1.1	0.66	1.6
Real rmse	0.19							
Adj. sd	0.28							
Separation	3.07							
Item reliability	0.79							

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

S.S. contributed to building the theoretical framework, methodology and interpretation of the results, and R.A. contributed to building tools, statistical analysis and review. All authors have read and agreed to the published version of the manuscript.

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