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Mediation/moderation effects of engagement, foreign language enjoyment, and ambiguity tolerance in metaverse-based foreign language learning

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Abstract

This study investigates how engagement (E), foreign language enjoyment (FLE), and ambiguity tolerance (AT) exert mediation/moderation in metaverse-based foreign language learning (FLL). Featuring augment/simulation-based experiences and self-fulfillment/external-control-oriented mechanics, metaverse provides virtualized interactive circumstances involving individuals' embodied presence/behaviors, aligning with FLL that emphasizes social interaction. Based on the quantified survey data, partial least squares structural equation modeling (PLS-SEM) analyses investigate the significance and positivity of the mediation/moderation relations. According to the results, E exerts fully positive mediation in the effect of intrinsic motivation (IM) on learning effectiveness (LE), FLE exerts partially positive mediation in the effect of classroom social climate (CSC) on E, and AT exerts negative moderation in the positive effect of E on LE. Notably, FLE exerts insignificant mediation in the effect of growth mindset (GM) on E. Therefore, efficient metaverse-based FLL requires synergies of affective factors, i.e., intrinsic motivation, perceptions of classroom social climate, moderate degrees of ambiguity tolerance, and engagement, for sustainable and long-term language learning progress in virtual interactive experiences. At the theoretical level, the findings extend the FLL-related models and advance the understanding of FLL. At the practical level, the findings provide references for more efficient metaverse implementations in FLL.

Keywords: Engagement, Foreign language enjoyment, Ambiguity tolerance, Metaverse, Foreign language learning

Introduction

Initially coined by Stephenson (1992), "metaverse" refers to a virtual-reality condition beyond real-life contexts (AlSaleem, 2023). Etymologically speaking, this word consists of "meta-" denoting a process of transcending the substance into the corresponding virtual form and "universe" indicating the existing world (Kye et al., 2021). As digital media and the Internet advance in functionality and accessibility, integrations of metaverse and digital platforms are issues worth investigating from the perspectives of efficiency and

innovation (AlSaleem, 2023). Among the fields for digital-platform-based metaverse implementation, education reflects the effects of metaverse on individuals' affective/behavioral/performative cultivations through interactions and communications in virtual settings (Qian et al., 2023). Although educators and researchers have accordingly been exploring the efficiency of educational technologies in learning, what differentiates metaverse from traditional digital technologies for educational purposes is that metaverse provides augments or simulations of the original situations and creates the corresponding experiences outside the traditional contexts (Kye et al., 2021; Puncreobutr et al., 2022).

Metaverse can meet the educational needs in higher-education situations (Dayoub, 2022; Kye et al., 2021) based on its emphases on social interactions in virtual settings (Qian et al., 2023), flexible knowledge acquisition through a balance between learning efforts and leisure (AlSaleem, 2023), and accessible resources beyond spatial restrictions (Al-Adwan et al., 2023). That compatibility between metaverse and higher education raises individuals' need to enhance digital literacy, i.e., the ability to skillfully utilize interaction-oriented techniques to attain learning goals (Gamelin et al., 2021), for efficient knowledge transfer and problem-solving (Qian et al., 2023). Since education is a reciprocal process rather than a receptive process where individuals just use digital technologies based on digital literacy, educators and researchers have been investigating the metaverse-based approach, i.e., the pedagogical approach to transforming original didactic procedures into virtual environments through digital technology (Al-Adwan et al., 2023; Qian et al., 2023), to boosting learning in specific discipline (Jovanović & Milpsavljević, 2022; Ryu et al., 2022). Notably, foreign language learning (FLL) is one situation where the metaverse-based approach can show its efficiency by promoting collaboration, problem-solving skills, and creativity (Shadiev & Wang, 2022).

Socio-cultural theory and constructivism theory are the theoretical rationales for the feasibility of metaverse in FLL. The socio-cultural theory emphasizes the essential role of interpersonal interactions in efficient and successful learning (Lantolf, 2000). Since metaverse can provide engaging experiences with synchronous interactions and competency-based training (AlSaleem, 2023), interaction-oriented experiences produced by metaverse are consistent with interaction as the premise of FLL according to the socio-cultural theory. Besides, according to the constructivism theory, learning is a substantially social and contextual procedure during which individuals actively generate, construct, systematize, and retrieve knowledge (Vygotsky, 1978). Since metaverse encourages individuals to construct language knowledge and discourses based on collaborative behaviors in virtual settings (Shadiev & Wang, 2022), metaverse is feasible in FLL by fostering volitional knowledge construction through social interaction.

Interactivity, embodiment, and persistence are the characteristics of metaverse learning related to engagement (Abu-Salih, 2022; Almarzouqi et al., 2022). Interactivity refers to how individuals can interact with objects, e.g., physical humans, avatars of humans, rubrics, and virtualized substances, to form metaverse experiences (Almarzouqi et al., 2022; Díaz et al., 2020). Embodiment refers to the process of symbolizing individuals' presence and behaviors (Makransky & Mayer, 2022). Persistence refers to the consistent operation of the metaverse components and settings through (re)connection to the virtual settings (Abu-Salih, 2022). Individuals' perceptions and

utilizations of interaction-oriented metaverse components contribute to engagement (Lee et al., 2022) as the predictor of behavioral/emotional/cognitive enhancement (Chiu, 2022). When the metaphorized forms can represent individuals' spontaneous need for change/progress, the individuals can unconsciously participate in the metaverse-based experiences, reflecting the association between embodiment and engagement (Kye et al., 2021). Continuity of the metaverse contributes to persistent functioning and effects of metaverse experiences based on sustainable engagement in metaverse learning (Almarzouqi et al., 2022). Since the three characteristics of metaverse learning are associated with engagement as a critical premise of FLL commitment and FLL outcome (Aparicio et al., 2021; Ghelichli et al., 2023), engagement is the hint to link metaverse to FLL.

Engagement contributes to easy adaptations to the metaverse technology (Liu & Hao, 2024) and the facilitation of learning (Zhang & Huang, 2024). Regarding FLL contexts, E is associated with foreign language enjoyment (FLE), i.e., volitional pleasure of learning and using foreign language (Lee, 2020), and ambiguity tolerance (AT), i.e., the degree of managing unfamiliar situations without frustration (McLain, 2009). While FLE maintains individuals' positive attitudes to learning for FLL progress (Li, 2023), AT debilitates engagement in metaverse-based FLL through potential interference of uncertainty in learning experiences (Paralkar & Knutson, 2023). Thus, E, FLE, and AT are the interrelated constructs and the critical factors conducive to efficient metaverse-based FLL associated with learning effectiveness (LE) (Al-Adwan et al., 2023), intrinsic motivation (IM) (Xiao & Hew, 2023), classroom social climate (CSC) (Mohammad Hossein et al., 2022), and growth mindset (GM) (Li, 2023).

However, few studies have simultaneously investigated how E, FLE, and AT are interrelated and how these constructs influence metaverse-based FLL, reflecting the research gap as a guide for the current study. Therefore, the objective of the current study is to investigate how engagement, foreign language enjoyment, and ambiguity tolerance, as interrelated constructs, exert predictive effects on metaverse-based foreign language learning, eliciting the following three research questions (RQs) and the corresponding hypotheses (Hs) based on the subsequent literature review.

RQ1 (related to H1-H3): How does engagement influence metaverse-based foreign language learning?

H1: In metaverse-based FLL, E significantly and positively predicts LE.

H2: In metaverse-based FLL, E significantly and positively mediates the effect of IM on LE.

H3: In metaverse-based FLL, IM significantly and positively predicts LE.

RQ2 (related to H4-H8): How does foreign language enjoyment influence metaverse-based foreign language learning?

H4: In metaverse-based FLL, FLE significantly and positively predicts E.

H5: In metaverse-based FLL, CSC significantly and positively predicts E.

H6: In metaverse-based FLL, FLE significantly and positively mediates the effect of CSC on E.

H7: In metaverse-based FLL, GM significantly and positively predicts E.

H8: In metaverse-based FLL, FLE significantly and positively mediates the effect of GM on E.

RQ3 (related to H9): How does ambiguity tolerance influence metaverse-based foreign language learning?

H9: In metaverse-based FLL, FLE significantly and negatively moderates the effect of E on LE.

Literature review

This section provides the theoretical evidence of metaverse-based FLL contexts and justifications for raising H1-H9.

Contexts of metaverse-based foreign language learning

Metaverse reflects a three-dimensional virtual reality where individuals are transformed into the corresponding avatars who conduct daily activities and economic life (Liu & Hao, 2024). For metaverse users, avatars enable individuals to engage in social and cultural activities by extending reality into virtual settings (Asiksoy, 2023). For metaverse experiences, virtual reality and reality interact and coevolve into unified and synergized learning situations (Han et al., 2023). These engaging features contribute to numerous applications of metaverse in educational contexts with distinctive merits, necessitating a classification of these applications according to the "augmentation versus simulation" and "inner world versus external world" dimensions (Kye et al., 2021).

The "augmentation versus simulation" dimension indicates whether the metaverse technology provides the virtual environments by implementing further information in the physical contexts (Kye et al., 2021), aligning with the core feature to differentiate metaverse from traditional digital technology in educational contexts (Puncreobutr et al., 2022). Augmentation technology provides new function(s) as complements of the existing real world (Ryu et al., 2024). In the augmented metaverse experiences, individuals can interact with the further information superimposed on the physical surroundings (Shu & Gu, 2023). In contrast, simulation technology provides a parallel virtualized form of the existing real world (Flores-Castaneda et al., 2024). In simulated metaverse experiences, individuals can perceive and participate in totally virtual experiences modeled from the corresponding real-life contexts (Onu et al., 2023).

The "inner world versus external world" dimension indicates whether the metaverse technology aims to prompt individuals' physical changes through internal intimation of the individuals' identities or external presentations of the desire for controlling information/context (Kye et al., 2021). Metaverse for the inner world emphasizes the identity fulfillment and behavioral maintenance/changes of an individual or object (Yang, 2023). Avatar and digital profiles are indispensable bridges between the physical individuals and the virtualized environments for task completion in the inner metaverse world (Hwang et al., 2023). In contrast, metaverse for the external world emphasizes the information presentation in the external aspect of the physical world (Jeon et al., 2024). Mechanics and detections inspire individuals to control the surrounding circumstances through the information virtualized from the corresponding physical forms (Maghaydah et al., 2024).

Integrating these two dimensions contributes to four metaverse subtypes: augmented reality, lifelogging, mirror world, and virtual reality (Kye et al., 2021). With the features of augmentation and external world, augmented reality refers to the metaverse application that expands the physical world into smart environments through location-aware

systems/networks/interfaces and layered information in real-life contexts (Kye et al., 2021). Augmented reality is applicable to contents that are essentially difficult to observe or explain, fields that require continuous practice/management, and materials that demand high costs/risk (Harrington, 2024). In FLL, augmented reality can be digital textbooks involving visualized presentations of substantially abstract contexts, prompt notes, interfaces based on clicking, or realistic presentations of virtualized objects (Kye et al., 2021).

With the features of augmentation and inner world, lifelogging refers to the metaverse application to capture, store, and share daily experiences/information about individuals or objects (Kye et al., 2021). In educational contexts, lifelogging enables individuals to volitionally participate in reciprocal networking and enhance adaptations based on customized feedback on learning achievement (Dwivedi et al., 2022). In FLL, lifelogging can be social media through which individuals communicate with others, participate in the topic-oriented language use processes, and perceive/judge/comprehend the illocutionary meanings through literal meanings of the shared contents (Celik & Baturay, 2024).

With the features of simulation and external world, mirror world refers to the metaverse applications that reflect the physical world regarding its appearance, information, and structure (Kye et al., 2021). Internet or mobile applications pave the paths for transferring real-life pedagogical activities into the corresponding virtualized processes with ontologically external class information (Singh, 2024). In FLL, mirror world can be real-time online classes conducted through online video conferencing platforms, which offer digitalized operations of interaction-oriented gathering for language knowledge receptions/productions (İbïlï et al., 2024).

With the features of simulation and inner world, virtual reality refers to the metaverse application involving a three-dimensional virtual world and digitalized data (Kye et al., 2021). Virtual reality for educational purposes prompts subconscious engagement in instant interactions between/among avatars that reflect the individuals themselves (Tsappi et al., 2024). In FLL, virtual reality can be online multiplayer games that metaphorize real-life classroom/communications into playable interactions based on entertaining images/settings/rubrics and transform individuals' external-stimulant-oriented actions into spontaneous behaviors to make progress (H.-J. Chen, 2023a, 2023b).

Overall, this part has presented the metaverse applications in FLL, which include augmented reality, lifelogging, mirror worlds, and virtual worlds. Smartphone networks, wearable devices, online conferencing applications, and serious games supporting instant multiplayer interactions are the platforms to implement these metaverse technologies in FLL. These applications provide evidence of metaverse-based FLL contexts.

Relations among E, LE, and IM from the perspective of metaverse-based foreign language learning

Engagement (E) refers to active involvement and absorption in the target experiences/procedures based on spontaneous concentration and volitional commitment to learning objectives/activities (Chiu, 2022). Engagement reflects individuals' subconscious and volitional involvement in the learning procedures (Singh, 2024), aligning with the engaging features of metaverse-based FLL regarding interactivity, embodiment, and persistence (Aparicio et al., 2021; Ghelichli et al., 2023).

The essential role of engagement in metaverse experiences is also reflected in the two metaverse dimensions. The "augmentation versus simulation" dimension necessitates the indispensable role of immersive experiences through superimpositions or parallel imitations, while the "internal world versus internal world" emphasizes the effects of engaging experiences on individuals' affective/behavioral/performative change orientations (Kye et al., 2021). Augmentation or simulation forms of metaverse experiences cultivate individuals' autonomy in processing/managing/controlling the learning conditions or their spontaneity in achieving learning goals through self-identification in the virtual settings (Flores-Castaneda et al., 2024; Ryu et al., 2024), reflecting the facilitating effects of engagement in metaverse experiences on learning attitudes/behaviors/performance (Celik & Baturay, 2024). These statements reflect the justification of selecting E as the construct related to metaverse-based FLL.

The facilitating effects of E on learning are reflected by the benefits of learning performance (Zhang & Huang, 2024). Learning effectiveness (LE), i.e., the degree to which a specific educational intervention is successful in producing the desired result(s) of learning, is the target construct to evaluate and quantify the potential benefits of pedagogical instruments/components/mechanics/experiences in learning (Al-Adwan et al., 2023; Liaw & Huang, 2016; Panigrahi et al., 2021). Since metaverse aims to produce purposeful activities/practices/interactions that require individuals' engagement to promote authentic language learning (AlSaleem, 2023; Lee et al., 2022), E is associated with LE in metaverse-based FLL. Additionally, engaging experiences enable individuals to receive, perceive, internalize, and surpass the provided activities for sustainable learning effectiveness (Xu et al., 2023) at the behavioral, emotional, cognitive, and agentic levels (Chiu, 2022; Fredricks et al., 2004; Jang et al., 2016; Reeve & Tseng, 2011). Metaverse provides immersive learning circumstances to inspire individuals' volitional participation in adaptive and self-directed activities, fulfilling the crucial premises of effective learning, goal attainment, and performance enhancement (Abu-Salih, 2022; Al-Adwan et al., 2023; Almarzouqi et al., 2022; AlSaleem, 2023; Aparicio et al., 2021; Dayoub, 2022; Díaz et al., 2020; İbİlİ et al., 2024; Qian et al., 2023). Thus, engagement exerts the hypothesized facilitating effects on learning effectiveness (Almulla, 2023; Qian et al., 2023), which provides the justification for H1: In metaverse-based FLL, E significantly and positively predicts LE.

Engagement is based on willingness/desire/volition (Shakhmalova & Zotova, 2023), suggesting that an affective construct predicts E. The influences of metaverse on FLL reflect the integration of affective cultivations, e.g., engagement and motivation (Almusharraf et al., 2023), and performative cultivations, e.g., self-regulated behaviors for interaction and problem-solving (Almulla, 2023; AlSaleem, 2023; Chen et al., 2024; Rashwan, 2023). Regarding the affective cultivations, metaverse involves the externally interest-stimulating components/mechanics, e.g., points, badges, and leaderboards, and internally encouraging motivators, e.g., a deep-level association between meaningfulness and behavioral change/progress (Chen et al., 2024), to guarantee engaging interactions and persistent involvement (Lashari et al., 2023). Regarding performative cultivations, affective cultivations contribute to individuals' facilitating attitudes and autonomy in reciprocal language uses through meaningful communications (Fortuna et al., 2023).

The association between the affective and performative cultivations reflects the predictive effects of motivating settings on engagement that facilitates FLL. Explicitly speaking, intrinsic motivation (IM), i.e., the perceived need to fulfill participation/completion/attainment for spontaneous interest/enjoyment (Pintrich et al., 1991, p. 9; Xiao & Hew, 2023), is the construct consistent with engagement that highlights spontaneous and volitional involvement (Chiu, 2022; Liu & Hao, 2024). Since intrinsically motivated states contribute to engagement through spontaneous pleasure and efficacy perception (Singh et al., 2022; Vezne et al., 2023), IM is assumed to predict E that influences LE, which implies that E mediates the effect of IM on LE and provides the justification for H2: In metaverse-based FLL, E significantly and positively mediates the effect of IM on LE. Besides, intrinsic motivation is conducive to the sustainable willingness to use language and enhance language mastery based on less language anxiety (Al-Adwan et al., 2023; Alamer et al., 2022; Rashwan, 2023; Singh et al., 2022). Since intrinsic motivation is a fundamental determinant of language proficiency (Alamer et al., 2022), IM is assumed to directly predict LE, which provides the justification for H3: In metaverse-based FLL, IM significantly and positively predicts LE.

Relations between E and FLE/CSC/GM/AT from the perspective of language learning experiences

The effects of metaverse on FFL are reflected through the affective states associated with engagement, the core feature of metaverse-based FLL. Foreign language enjoyment (FLE) refers to individuals' volition to use/learn foreign language and their facilitating psychological states to manage, overcome, and outperform challenges in FLL (Mohammad Hosseini et al., 2022). Since individuals' facilitating attitudinal states in educational contexts contribute to their volitional persistence in performing learning behaviors (Li, 2023), FLE as a psychological state is a potential predictor of spontaneous involvement in the metaverse-based FLL. The positive attitudes to language use and learning inspire individuals to perform active behaviors to pursue a balance between challenges and current knowledge level to avoid distractions and guarantee engagement in learning (Jiang & Dewaele, 2019). Since FLE can provide affective support for the cultivation of autonomy, competence, and relatedness, i.e., the qualities for engagement (Guo, 2021; Mohammad Hosseini et al., 2022), FLE is assumed to exert positive effects on E in FLL contexts, which provides the justification for H4: In metaverse-based FLL, FLE significantly and positively predicts E.

Classroom social climate (CSC), i.e., the degree to which learners establish and maintain relationships with teachers based on social interactions (Mohammad Hosseini et al., 2022), is an engagement-related affective construct regarding individuals' reactions to the learning atmosphere. CSC encourages individuals to cultivate volitional willingness to perform social-interactive behaviors and exert voluntary efforts to make self-regulated progress (Joe et al., 2017; Lee, 2020), aligning with the requirement of social interaction for successful language learning according to socio-cultural theory (Shadiev & Wang, 2022; Vygotsky, 1978). CSC is compatible with metaverse-based FLL because metaverse offers collaborative language learning for secure and adaptive pedagogical activities in virtual settings (Jovanović & Milosavljević, 2022; Ryu et al., 2022). Learning environments with higher CSC contribute to more engagement in pedagogical activities

for greater knowledge productivity (Schiller et al., 2024), reflecting the potential predictive effects of CSC on E in language learning circumstances. That statement provides the justification for H5: In metaverse-based FLL, CSC significantly and positively predicts E. Additionally, interaction-oriented learning inculcates individuals with positive emotions for long-term persistence and sustainable development (J.-M. Dewaele & L. Dewaele, 2017; Lee, 2020; Li et al., 2021; Makransky & Mayer, 2022; Shadiev & Wang, 2022). Since FLE happens in collaborative learning circumstances involving interactive and immersive activities (Almarzouqi et al., 2022; J.-M. Dewaele & L. Dewaele, 2017; Makransky & Mayer, 2022; Qian et al., 2023), the cultivation of positive emotions through CSC reflects the potential predictive effects of CSC on FLE, i.e., the construct of affective states beneficial for language learning (Li, 2023). Integrating the effects of CSC on FLE and the effects of FLE on E provides the justification for H6: In metaverse-based FLL, FLE significantly and positively mediates the effect of CSC on E.

Growth mindset (GM), i.e., individuals' belief that language proficiency is improvable through external factors (e.g., efforts, strategies, and feedback), is another engagement-related affective construct regarding perceptions of language-learning success attribution (Hwang et al., 2023). Although the stability of GM for FLL is subject to language learning background, conditions for social interactions (Mercer & Ryan, 2010), GM enables individuals to venture beyond their comfort zone for substantial growth in authentic language proficiency and adaptability to socio-cultural settings (Khajavy et al., 2022; Papi et al., 2019). Since GM-driven individuals' facilitating attribution of FLL success contributes to their sustainable involvement in authentic language use as the reflection of persistent and substantial engagement in FLL (Li, 2023), GM is assumed to exert predictive effects on E in FLL contexts, which provides the justification for H7: In metaverse-based FLL, GM significantly and positively predicts E. Additionally, GM-driven individuals can reinforce the associations between learning efforts and enhancement in FLL to achieve satisfaction and enjoyment through their ability to deal with language learning challenges (Bai & Wang, 2020; Dweck, 2017), implying the assumed effects of GM on FLE highlighting enjoyment (Li, 2023). Integrating the effects of GM on FLE and the effects of FLE on E provides the justification for H8: In metaverse-based FLL, FLE significantly and positively mediates the effect of GM on E.

Ambiguity tolerance (AT), i.e., the degree to which individuals endure unpredictable and unfamiliar language-use contexts without frustration or discomfort, is another engagement-related construct regarding the potential debilitation of individuals' involvement at the psychological and social levels (Yu et al., 2022). From the psychological perspective, AT would distract individuals' attention from language comprehension/production to anxious identifications of (un)familiarity and (un)certainty (Chu et al., 2015; Moul et al., 2023). Excessively AT-oriented behaviors would lead to debilitating states for managing intricate language-use situations, e.g., timid, silenced, alienated, and demotivated states (Paralkar & Knutson, 2023), reflecting the adverse effects of AT on engagement in flexible learning procedures and autonomy in dealing with uncertainty (Moul et al., 2023). From the social perspective, AT would decrease the sense of belonging to the educational contexts (Paralkar & Knutson, 2023). Excessive AT would lead to anxiety that hinders conversational/interactive hints and social presence as indispensable factors for engagement (Aslan & Thompson, 2021; Jiang et al., 2023). Apart from the

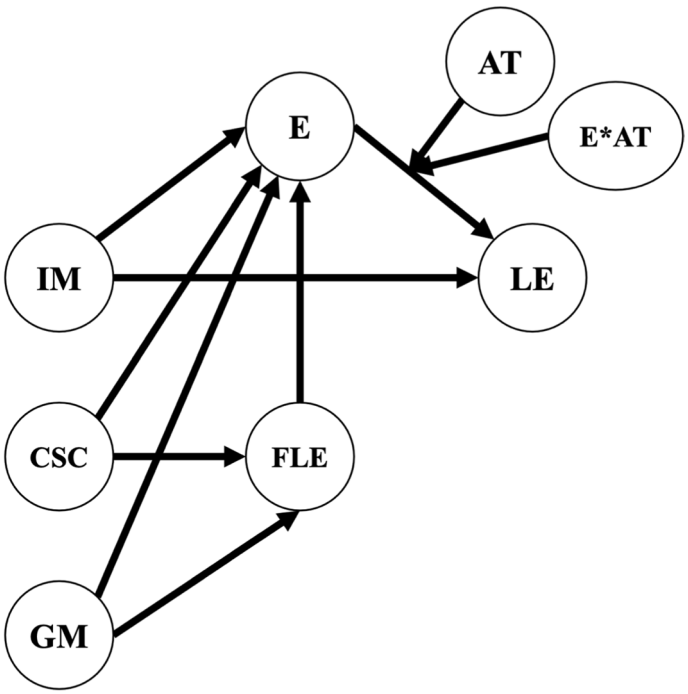

Fig. 1 Conceptual model with the involved constructs

potentially negative relation between AT and E, AT is assumed to be related to LE. Since AT influences the positivity and strength of the correlation between autonomy, i.e., one essential premise of engagement, and language learning outcomes (Chen, 2023a, 2023b), AT is related to LE as the quantified FLL outcomes especially through the interventions of educational technologies (Al-Adwan et al., 2023; Panigrahi et al., 2021). Integrating the debilitating relation between AT and E, the influence of AT in the correlation involving E, and the facilitating effects of E on LE implies the potentially negative moderation of AT in the effects of E on LE. That statement elicits H9: In metaverse-based FLL, FLE significantly and negatively moderates the effect of E on LE.

Thus far, 2.2 and 2.3 have presented the justifications for the hypothesized relations among E, LE, IM, FLE, CSC, GM, and AT (see Fig. 1). These relations form the model of how metaverse influences FLL through affective cultivations. The four types of metaverse applications mentioned in 2.1 provide the metaverse-based FLL contexts for this model.

Methodology

This section describes methodological considerations for this study.

Research method overview

This study conducts a quantitative method through a within-group experiment involving a survey to analyze the relations among affective states and learning effectiveness in metaverse-based FLL. The research guidelines of Saunders et al., (2019, p. 128) provide the rationales for selecting this method. Since this study aims to generalize assertions (relations between/among the constructs related to metaverse-based FLL) from

observable outputs (significance and effect size for these relations), this study aligns with positivism as the philosophical assumption (Saunders et al., 2019, p. 144). Since this study aims to infer a conclusion (how metaverse influences FLL through affective cultivations) from reasoning (descriptions, interpretations, and discussions of the results), this study aligns with deduction as the theory development process (Saunders et al., 2019, p. 176). The within-group experiment design plans to investigate the relations among the metaverse-FLL-related constructs without grouping (Saunders et al., 2019, pp. 178 & 212). The survey design is a questionnaire, i.e., the technique for deductive and quantitative designs, to quantify the involved constructs (Saunders et al., 2019, pp. 178, 193, & 564).

Research tools and involved variables

Corresponding with the research design, the author conducted a survey. The research tools for this survey involved an online hybrid questionnaire, Wenjuanxing (https://www.wjx.cn) as the platform for designing/uploading/sending/receiving the online questionnaires, WeChat and QQ as the platforms to share the online questionnaires, and RStudio as the analytical platform for the survey results.

The online hybrid questionnaire includes two sections: (a) participants' demographic information and (b) self-ratings for the constructs related to metaverse-based foreign language learning. Section (a) involves the records of participants' consent for participation, gender (the variable "Gender"), age ("Age"), fields of study ("Field"), and subtypes of applying metaverse to foreign language learning ("Deployment"). Section (b) involves the measurements of E, LE, IM, FLE, CSC, GM, and AT, each of which is measured by four self-rating items (e.g., IM measured by IM1-IM4) on a 5-Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree) (see Appendix). These questions are adapted from past study questionnaires to guarantee the accuracy of the content of the measurements. Questions for E, LE, IM, FLE, CSC, GM, and AT are adapted from the questionnaires from Jang et al. (2016), Liaw and Huang (2016), Pintrich et al., (1991, p. 9), Jiang and Dewaele (2019), Joe et al. (2017), Papi et al. (2019), and Chu et al. (2015), respectively. Self-rating designs enable the participants to quantify their construct states through the estimated consistency between their perceptions and the question item descriptions. Further statistical analyses were conducted to confirm the reliability and validity of the measures (see Sect. "Reflective measurement models").

Wenjuanxing was the digital platform that enabled the author to input the question items mentioned above and test whether the designed questionnaire could normally work. After designing the questionnaire and checking the settings, the author shared the online questionnaire link to the WeChat and QQ groups. When the participants voluntarily consented to participate in the survey, i.e., to agree to the consent statement, "I agree to participate in this experiment voluntarily and contribute my test performances and responses to the researcher only for the purposes of academic research. I understand that the results are anonymized and will be kept confidential in use.", they finished the questions in sections (a) and (b). Considering the ethical statement, the survey did not record any information irrelevant to the research, and the author ensured that the participants were aware of the survey objective, i.e., measuring and analyzing the relations between/among constructs related to metaverse-based FLL, before the participants

filled out the questionnaire. The survey results were analyzed on the platform RStudio (see Sect. "Statistically analytical approach").

Research participants, contexts, and procedure

Since metaverse is consistent with higher education highlighting interaction-oriented procedures (Gamelin et al., 2021) and problem-solving-oriented knowledge mastery (Qian et al., 2023), the author chose university students as the representative population for the survey. The survey finally recruited 686 participants, and section a) of the questionnaire recorded their demographic information as follows (see Table 1). Regarding "Gender", the participants are 377 females and 309 males. Regarding "Age", the participants' ages range from 19 to 28 (mean (M) = 23.109, standard deviation (SD) = 2.788). Regarding "Field", the participants' fields of study include philosophical sciences, economic sciences, law, education, literature, history, natural sciences, engineering, agronomy, medicine, management sciences, and arts. Regarding "Deployment", the participants' utilizations of metaverse in foreign language learning include the subtypes of metaverse application presented in 2.1: augmented reality (established smart

Table 1 Demographic information of the participants

Demographic variable		Frequency	Percent (%)	Cumulative percent (%)
Gender	Female	377	55.0	55.0
	Male	309	45.0	100.0
Age	19	89	13.0	13.0
	20	88	12.8	25.8
	21	27	3.9	29.7
	22	94	13.7	43.4
	23	88	12.8	56.3
	24	71	10.3	66.6
	25	54	7.9	74.5
	26	76	11.1	85.6
	27	59	8.6	94.2
	28	40	5.8	100.0
Field	Philosophical sciences	53	7.7	7.7
	Economic sciences	43	6.3	14.0
	Law	67	9.8	23.8
	Education	62	9.0	32.8
	Literature	56	8.2	41.0
	History	49	7.1	48.1
	Natural sciences	66	9.6	57.7
	Engineering	57	8.3	66.0
	Agronomy	63	9.2	75.2
	Medicine	56	8.2	83.4
	Management sciences	59	8.6	92.0
	Arts	55	8.0	100.0
Deployment	Augmented reality	157	22.9	22.9
	Lifelogging	166	24.2	47.1
	Mirror world	179	26.1	73.2
	Virtual reality	184	26.8	100.0

environment based on location-based systems/networks/interfaces), lifelogging (technology to capture, store, and share daily experiences/information), mirror world (environment reflecting the physical world through appearance, information, and structure), and virtual reality (three-dimensional virtual world with digital data).

Considering the foreign language learning context, since the representative population is university students, university curricula allowing the use of educational technologies are the participants' foreign language learning contexts. Featuring interactive relationships between students and teachers, university curricula are the target contexts for foreign language learning through idea-stimulating communications and cooperation-stimulating settings, reflecting enhancing foreign language mastery through interaction (Shadiev & Wang, 2022). Besides, foreign languages in the research context include non-native languages for general uses, i.e., for general communication, or specified uses, i.e., for defining the terms or discussing the ideas specified in the study fields. Additionally, since this survey investigates the metaverse applications, the university curriculum contexts should be compatible with the use of educational technologies, e.g., mobile phone applications or digital teaching platforms, that enable students to experience augmentation/simulation emphasizing internal intimation or desire for control (Kye et al., 2021) (see Sect. "Contexts of metaverse-based foreign language learning"), reflecting the potential benefits of educational technologies through interactive and self-development-oriented settings (Xu et al., 2023).

The research procedure involved data collection and data analyses. The data collection lasted 4 weeks (from November 20, 2023, to December 17, 2023). Having finished designing the online questionnaire on the platform Wenjuanxing, the author sent the link to the WeChat and QQ groups involving university students. Participants' voluntary consent to participate in the survey enabled them to continue with the survey. When the data collection ended, the author downloaded and organized the data (see Supplementary Material) for the data analyses.

Notably, before the data analyses, it was necessary to identify whether the nominal/interval-scale demographic variables, i.e., "Gender", "Age", "Field", and "Deployment", impacted the measures of the metaverse-FLL-related constructs. Thus, the author performed the Kruskal–Wallis H test to analyze whether group divisions by "Gender", "Age", "Field", and "Deployment" led to significant differences in the measures of the metaverse-FLL-related measures. According to the Kruskal–Wallis H test results (see Appendix), since all the significance levels are greater than 0.050, the metaverse-FLL-related measures are not significantly different among the groups divided by "Gender", "Age", "Field", and "Development". These Kruskal–Wallis H test findings confirm that the demographic variables do not lead to great variations in the results in participants' self-rated states of the metaverse-FLL-related constructs, providing the statistical rationale for further analyses through RStudio (see Sect. "Statistically analytical approach").

Statistically analytical approach

Structural equation modeling (SEM) is the statistically analytical approach that models and estimates the relations between/among the constructs based on measurement error inherent in indicators (Hair et al., 2022, p. 4) because the collected data involves multiple indicator variables, i.e., directly measured variables (the self-rating 5-Likert

items), as one of the measures of the corresponding constructs, i.e., variables not directly measurable (E, LE, IM, FLE, CSC, GM, and AT). Regarding the statistical technique for the approach, since this study aims to extend the established theories about metaverse-based FLL and complies with deduction for theory development (Saunders et al., 2019, p. 176), the partial least squares SEM (PLS-SEM) method is the statistical technique to explain the causal relations between/among the constructs and interpret the potential theoretical extension (Hair et al., 2022, p. 4). Regarding the analytical platform, RStudio is the integrated development environment for PLS-SEM analyses with the R language (Hair et al., 2021, p. 32).

The PLS-SEM analyses estimate (1) measurement models, (2) structural model, (3) mediations, and (4) moderation. First, the estimation of measurement models investigates the relations between the constructs and their indicators, i.e., the questionnaire items (Hair et al., 2022, p. 41) and presents the reliability and validity issues (Hair et al., 2021, p. 76). Regarding the subtype of the measurement model, since the items are mutually interchangeable for the corresponding constructs that reflect the traits in metaverse-based FLL, the current measurement model investigations focus on reflective measurement models (Hair et al., 2022, pp. 51 & 56). Besides, the estimation of structural model, including collinearity issues, structural model relationships, and explanatory/in-sample predictive power (Hair et al., 2021, p. 116), investigates the significance and effect size of the relations between/among the constructs and the persuasiveness of these findings (Hair et al., 2022, p. 41). Additionally, the estimation of mediation analyses investigates whether and how the mediator constructs, i.e., E and FLE for this study, significantly bridge the effect of the exogenous construct on the endogenous construct. The estimation (e.g., for IM → E → LE) includes the direct effects, i.e., the relations between two constructs with a single arrow ("p_1" for IM → E, "p_2"for E → LE, "p_1*p_2" as the total direct effect), indirect effect, i.e., a sequence visualized in multiple arrows and reflecting multiple direct effects ("p_3" for IM → LE), and total effect, i.e., the sum of the total direct effect and the indirect effect ("p_1*$p_2 + p_3$") (Hair et al., 2022, pp. 229–230). Furthermore, the estimation of moderation investigates whether and how the moderator construct, i.e., AT for this study, significantly influences the strength of the relation between the exogenous and endogenous constructs. The estimation (for AT in the effect of E on LE) includes the effects of the moderator (AT) and the interaction term, i.e., the construct covering the product of the exogenous construct and the moderator (E*AT) (Hair et al., 2022, pp. 247–248).

Replication of the study

This study can be replicated in the contexts aiming to investigate the potential relationships among engagement, learning effectiveness, intrinsic motivation, foreign language enjoyment, classroom social climate, growth mindset, and ambiguity tolerance in metaverse foreign language learning. The research aim can be further specified into the investigation of the potential mediating/moderating effects of engagement, foreign language enjoyment, and ambiguity tolerance on the other constructs related to metaverse foreign language learning (as shown in H1-H9), paving the path for extending the theories about metaverse-based foreign language learning.

The methodology regarding research tools, participant recruitment, and procedure can be replicated. The research tool includes an online questionnaire involving demographic information recording (e.g., gender, age, field of study, and the approach to applying metaverse to foreign language learning) and 5-Likert self-rating questions measuring the variables mentioned above. The sources of these self-rating items include Jang et al. (2016), Liaw and Huang (2016), Pintrich et al., (1991, p. 9), Jiang and Dewaele (2019), Joe et al. (2017), Papi et al. (2019), and Chu et al. (2015). The online questionnaire can be designed on the Wenjuanxing platform and sent to the WeChat/QQ groups for data collection. Participants are university students with educational-technology-equipped university curricular experiences in foreign language learning for general/specific uses. Educational technology is the contextual factor for the students to experience metaverse applications (augmentation/simulation based on internal imitation/stimulation for controlling) to foreign language learning. Regarding the research procedure, the survey lasts about 4 weeks for participants' responses. The participants who voluntarily consent to participate in the survey can complete the online questionnaire. The participants' responses are collected and organized for subsequent statistical analyses.

Data analyses are conducted on the RStudio platform. Having confirmed that the group divisions by the demographic variables do not lead to significant differences in the measures of the metaverse-related foreign language learning constructs through the Kruskal–Wallis H test, the researcher can conduct PLS-SEM analyses on RStudio to estimate the relationships among the constructs that cannot be directly measurable, i.e., all the metaverse-related foreign language learning constructs. During the PLS-SEM analyses based on the conceptual framework (see Fig. 1), the researcher can estimate the reflective measurement models, structural model, mediation effects of engagement/foreign language enjoyment, and moderation effect of ambiguity tolerance.

The results (see Sect. "Results", Tables 1, 2, 3, 4, 5, 6, and Figs. 2, 3) are the evidence to test H1-H9 and interpret how metaverse can enhance foreign language learning in higher education contexts. The documentation of this study can provide references for implementations. The descriptive statistics of the involved constructs are available in "Appendix". The data set for this study is available in "Supplementary Material".

Results

This section reports the results of PLS-SEM analyses to test the hypotheses.

Reflective measurement models

This part focuses on the reliability and validity of how questionnaire items measure the corresponding constructs. Analyses of reliability include indicator reliability and composite reliability (see Table 2 & Fig. 2). The squared values of indicator loadings are the measures of indicator reliability, i.e., how precisely the construct explains the corresponding indicators' variances (Hair et al., 2022, p. 117). Cronbach's alpha, reliability coefficient rhoA, and rhoC measure composite reliability, i.e., how indicators of the same construct are associated with each other (Hair et al., 2022, pp. 118–119). The findings are as follows.

Table 2 Summary of the reliability measures

Construct	Item	Indicator loading	Indicator reliability	Composite reliability		
				alpha	rhoA	rhoC
IM	IM1	0.865	0.747	0.870	0.878	0.911
	IM2	0.864	0.746			
	IM3	0.786	0.618			
	IM4	0.876	0.767			
CSC	CSC1	0.785	0.616	0.813	0.821	0.876
	CSC2	0.813	0.661			
	CSC3	0.811	0.658			
	CSC4	0.787	0.619			
GM	GM1	0.843	0.711	0.892	0.902	0.925
	GM2	0.860	0.740			
	GM3	0.874	0.764			
	GM4	0.896	0.802			
FLE	FLE1	0.810	0.656	0.831	0.836	0.888
	FLE2	0.814	0.663			
	FLE3	0.878	0.772			
	FLE4	0.754	0.569			
E	E1	0.859	0.737	0.871	0.873	0.912
	E2	0.870	0.756			
	E3	0.873	0.762			
	E4	0.795	0.633			
LE	LE1	0.839	0.703	0.844	0.853	0.896
	LE2	0.865	0.749			
	LE3	0.789	0.622			
	LE4	0.883	0.779			
AT	AT1	0.785	0.616	0.866	0.869	0.909
	AT2	0.790	0.624			
	AT3	0.885	0.784			
	AT4	0.840	0.706			
E*AT	E*AT_intxn	1.365	1.864	1.000	1.000	1.000

- All factor loadings are acceptable for the values > 0.708.
- All indicator reliabilities, i.e., squared values of the corresponding factor loading values, are acceptable for the values > 0.500.
- Acceptable indicator reliability values indicate that the measures meet the demand for indicator reliability (Hair et al., 2021, pp. 77 & 83).
- All Cronbach's alpha values are acceptable for the values > 0.700.
- All rhoA values are acceptable for the values > 0.700.
- All rhoC values are acceptable because they are in [0.600–0.700].
- All measures of composite reliability exceed the threshold visualized as the horizontal dashed line (see Fig. 2) (Hair et al., 2021, p. 84).
- Acceptable values of Cronbach's alpha, rhoA, and rhoC indicate that the measures meet the demand for composite reliability (Hair et al., 2021, pp. 77–78).

Table 3 Summary of the validity measures

Construct	Convergent validity	Discriminant validity: HTMT value (upper boundary of the 90% CI)							
	AVE	IM	CSC	GM	FLE	E	AT	E*AT	LE
IM	0.719	–	0.634 (0.702)	0.435 (0.530)	0.701 (0.755)	0.703 (0.754)	0.573 (0.636)	0.211 (0.327)	0.450 (0.513)
CSC	0.638	–	–	0.611 (0.685)	0.691 (0.764)	0.621 (0.694)	0.588 (0.664)	0.091 (0.192)	0.437 (0.512)
GM	0.754	–	–	–	0.372 (0.463)	0.365 (0.452)	0.299 (0.390)	0.097 (0.199)	0.277 (0.358)
FLE	0.665	–	–	–	–	0.722 (0.779)	0.651 (0.712)	0.163 (0.255)	0.546 (0.607)
E	0.722	–	–	–	-	–	0.776 (0.826)	0.345 (0.438)	0.698 (0.750)
AT	0.683	–	–	–	–	–	–	0.282 (0.362)	0.569 (0.632)
E*AT	1.000	–	–	–	–	–	–	–	0.145 (0.223)
LE	0.713	–	–	–	–	–	–	–	-

AVE: average variance extracted

HTMT: heterotrait-monotrait ratio

CI: confidence interval

The upper boundary of the 90% CI corresponds with the path from the row construct to the column construct, e.g., RF → SE

Analyses of validity include convergent validity and discriminant validity (see Table 3). Average variance extracted (AVE) measures convergent validity, i.e., how indicators positively correlate with alternative indicators of the same construct (Hair et al., 2022, p. 120). Heterotrait-monotrait ratio (HTMT) measures discriminant validity, i.e., how a construct is distinguishable from other constructs (Hair et al., 2022, pp. 120 & 122). The findings are as follows.

- All AVE values are acceptable for the values > 0.500, confirming the convergent validity of the measurements (Hair et al., 2021, pp. 78 & 85).
- All HTMT values are acceptable for the values < 0.850, confirming the divergent validity of the measurements (Hair et al., 2021, pp. 79–80).

Overall, all questionnaire items can provide precise and accurate measurements of the corresponding constructs.

Structural model

This part focuses on collinearity issues, structural model relationships, and explanatory/in-sample predictive power. Variance inflation factor (VIF) is the measure of collinearity issues, i.e., strong correlations between the exogenous constructs (see Table 4) (Hair et al., 2021, p. 117). The findings are as follows.

- All VIF values are acceptable for the values < 3.000.
- Acceptable VIF values indicate that all exogenous constructs do not excessively correlate with each other or produce biased estimates for the corresponding endogenous constructs (Hair et al., 2021, pp. 117 & 191).

Table 4 Measures to identify collinearity issues and explanatory power

	Exogenous construct	Endogenous construct		
		E	LE	FLE
Variance inflation factor (VIF)	IM	1.757	1.641	–
	CSC	1.924	–	1.368
	GM	1.400	–	1.368
	FLE	1.827	–	–
	E	–	2.315	–
	AT	–	1.859	–
	E*AT	–	1.120	–
R^2		0.487	0.397	0.334
Adjusted R^2		0.484	0.393	0.332

- This structural model does not present collinearity issues (Hair et al., 2021, p. 124).

Analyses of structural model relationships include significance and strength of the effect paths (see Table 5). T statistics > 1.960 or < -1.960 at a significance level of 5% (Hair et al., 2021, p. 94) and 95% confidence interval (95% CI) that does not cover the value zero (Hair et al., 2021, p. 117) confirm significance in the effect path. The findings are as follows.

- Three hypothesized positive direct-effect paths: "IM → LE", "GM → FLE", and "GM → E" and one hypothesized positive indirect-effect path: "GM → E" are insignificant due to t-statistics values < 1.960 and 95% CIs that cover the zero value.

Table 5 Significance and strength of the paths

Path	Original ratio estimates	Bootstrap mean ratio estimates	Bootstrapped mean SD	T Statistics	95% CI	
					Lower boundary	Upper boundary
Direct-effect paths						
IM → E	0.332	0.331	0.043	7.658	0.260	0.402
IM → LE	0.014	0.014	0.040	0.343	− 0.051	0.080
CSC → FLE	0.558	0.559	0.041	13.663	0.491	0.624
CSC → E	0.161	0.161	0.045	3.595	0.087	0.235
GM → FLE	0.037	0.038	0.044	0.829	− 0.033	0.113
GM → E	0.008	0.008	0.032	0.257	− 0.044	0.061
FLE → E	0.318	0.319	0.048	6.667	0.242	0.399
E → LE	0.527	0.528	0.050	10.457	0.444	0.610
AT → LE	− 0.156	− 0.156	0.047	− 3.323	− 0.232	− 0.079
E*AT → LE	− 0.053	− 0.052	0.027	− 1.949	− 0.097	− 0.007
Indirect-effect paths						
IM → LE	0.189	0.189	0.044	4.333	0.117	0.260
CSC → E	0.339	0.340	0.043	7.797	0.269	0.411
GM → E	0.020	0.020	0.036	0.556	− 0.037	0.080

SD standard deviation, *CI* confidence interval

- The rest of the hypothesized positive effect paths are significant due to t-statistics values > 1.960 and 95% CIs not covering the zero value.
- All hypothesized negative effect paths, i.e., "AT → LE" and "E*AT → LE", are significant due to due to t-statistics values < -1.960 and 95% CIs that do not cover the zero value.

Then, the author analyzes the strengths of the significant effect paths. Ratio estimates closer to + 1 or -1 indicate strong positive or negative relationships between the exogenous and endogenous constructs (Hair et al., 2021, p. 118). The findings of the bootstrap mean ratio (BMR) estimates are as follows.

- For the significant direct-effect paths involving E as the endogenous construct, the effect strengths are IM (BMR = 0.331) > FLE (BMR = 0.319) > CSC (BMR = 0.161).
- In the only significant total-effect path involving E as the endogenous construct, i.e., "CSC → E", CSC exerts a strong effect (BMR = 0.340).
- In the only significant direct-effect paths involving FLE as the endogenous construct, i.e., "CSC → FLE", CSC exerts a strong effect (BMR = 0.559).
- For the significant direct-effect paths involving LE as the endogenous construct, E exerts a strongly positive effect (BMR = 0.528), while AT and E*AT exert moderately negative (BMR = -0.156) and weakly negative (BMR = -0.052) effects.
- In the only significant total-effect path involving LE as the endogenous construct, i.e., "IM → LE", IM exerts a moderate effect (BMR = 0.189).

The author analyses the explanatory power to investigate how the aforementioned structural models fit the collected data (see Table 4) (Hair et al., 2022, pp. 194–195). The coefficient of determination (R^2) value measures the explanatory power based on the variance in the endogenous constructs explained by the corresponding exogenous constructs (Hair et al., 2022, p. 195). The findings are as follows.

- The R^2 values for E, LE, and FLE range in [0.250–0.500], reflecting moderate explanatory/in-sample predictive powers for these endogenous constructs (Hair et al., 2021, p. 118).
- The adjusted R^2 values for E, LE, and FLE range in [0.250–0.500], reflecting moderate explanatory/in-sample predictive powers for these endogenous constructs (Hair et al., 2021, p. 118).

Overall, the structural model that does not reveal collinearity presents moderate explanatory power. The significance and strengths of the effect paths pave the path for mediation and moderation analyses.

Mediation analyses

The analyses of the structural model output six mediation sub-models (a-f) (see Table 6). The characterization process of these mediation sub-models proceeds in three steps: (1) identifying indirect effect, (2) identifying direct effect, and (3) identifying the total direct

Table 6 Results of the mediation analyses

Sub-model		Original ratio estimates	Bootstrap mean ratio estimates	Bootstrapped mean SD	T Statistics	95% CI	
						Lower boundary	Upper boundary
Step 1: Indirect effect							
a	IM → E → LE	0.175	0.175	0.028	6.218	0.122	0.232
b	CSC → FLE → E	0.178	0.179	0.031	5.710	0.121	0.242
c	GM → FLE → E	0.012	0.012	0.014	0.823	− 0.016	0.040
d	CSC → FLE → E → LE	0.094	0.095	0.019	4.879	0.060	0.135
e	GM → FLE → E → LE	0.006	0.006	0.007	0.822	− 0.008	0.021
f	FLE → E → LE	0.168	0.169	0.031	5.461	0.112	0.232
Step 2: Direct effect							
a	IM → LE	0.014	0.014	0.040	0.343	− 0.051	0.080
b	CSC → E	0.161	0.161	0.045	3.595	0.087	0.235
c	GM → E	0.008	0.008	0.032	0.257	− 0.044	0.061
d	CSC → LE	–					
e	GM → LE	–					
f	FLE → LE	–					
Step 3: Effects within one mediation sub-model							
Sub-model		Effect			Estimates	Product value	
b	CSC → FLE → E	Sum direct effect	CSC → FLE	0.558	0.179	0.029	
			FLE → E	0.318			
		Indirect effect	CSC → E	0.161	0.161		
Characterization of mediation							
Sub-model		Is the path significant in Step 1?	Is the path significant in Step 2?	Is the product value positive in Step 3?		Mediation type	
a	IM → E → LE	Yes	No	–		Full mediation	
b	CSC → FLE → E	Yes	Yes	Yes		Complementary partial mediation	
c	GM → FLE → E	No	No	–		No effect	
d	CSC → FLE → E → LE	Yes	–	–		–	
e	GM → FLE → E → LE	No	–	–		–	
f	FLE → E → LE	Yes	–	–		–	

SD standard deviation, *CI* confidence interval

effect and indirect effect within one mediation sub-model (Hair et al., 2022, p. 235). The results are as follows.

Step 1 investigates the significance of the indirect effects and produces the following findings.

- The hypothesized positive indirect-effect models (c) and (e) reveal insignificant effects due to the t-statistics < 1.960 and 95% CIs that cover the zero points.
- Insignificant sub-models (c) and (e) in step 1 indicate that E and/or FLE do not significantly mediate the effect paths involving GM as the exogenous construct or E/LE as the endogenous constructs.

- The rest hypothesized positive indirect-effect models reveal significant effects due to the t-statistics > 1.960 and 95% CIs that do not cover the zero points.
- Significant sub-models (a), (b), (d), and (f) indicate that E and/or FLE significantly mediate the effect paths involving IM/CSC/FLE as the exogenous construct or E/LE as the endogenous constructs.

Step 2 investigates the significance of the direct effects, and Step 3 addresses the effects within the significant sub-model in Step 2. These steps produce the following findings.

- In step 2, the author excludes the sub-models (d), (e), and (f) because they do not belong to the hypothesized relations (see Fig. 1).
- Only sub-model (b) in step 2 reveals the significant indirect effect from exogenous construct CSC to endogenous construct E through mediator FLE.
- In step 3 and within sub-model (b), the total direct effect ("p_1*p_2") is 0.179 > 0, and the indirect effect ("p_3") is 0.161 > 0. The product value of these effects is 0.029 > 0.

The aforementioned steps provide the criteria for mediation characterizations (Hair et al., 2022, p. 234).

- For sub-model (a), IM exerts a significant indirect effect on LE through E, but IM exerts an insignificant direct effect on LE. Thus, sub-model a) reflects a full mediation of E in the effect of IM on LE.
- For sub-model (b), CSC exerts a significant indirect effect on E through FLE, and CSC exerts an insignificant direct effect on FLE. Since both total direct and indirect effects are positive within sub-model (b), this model reflects a complementary partial mediation of FLE in the effect of CSC on E.
- For sub-model (c), GM exerts an insignificant indirect effect on E through FLE, and GM exerts an insignificant direct effect on E. Thus, sub-model c) reflects no mediation of FLE in the effect of GM on E.
- For sub-model (d), CSC exerts a significant indirect effect on LE through FLE and E.
- For sub-model (e), GM exerts an insignificant indirect effect on LE through FLE and E.
- For sub-model (f), FLE exerts a significant indirect effect on LE through E.
- Further investigations for sub-models (d), (e), and (f) are not performed because they do not belong to the hypothesized mediation relations.

Moderation analysis

The moderation analysis concentrates on how the moderator (AT) affects the relation between the exogenous construct (E) and endogenous construct (LE) (see Table 5 & Fig. 3) (Hair et al., 2021, p. 163). The findings are as follows.

- AT exerts a significant direct effect on E (BMR = − 0.156), and E*AT exerts significant direct effects on E (BMR = − 0.052) (see Table 5). These negative effects are consistent with the hypothesized negative relations.

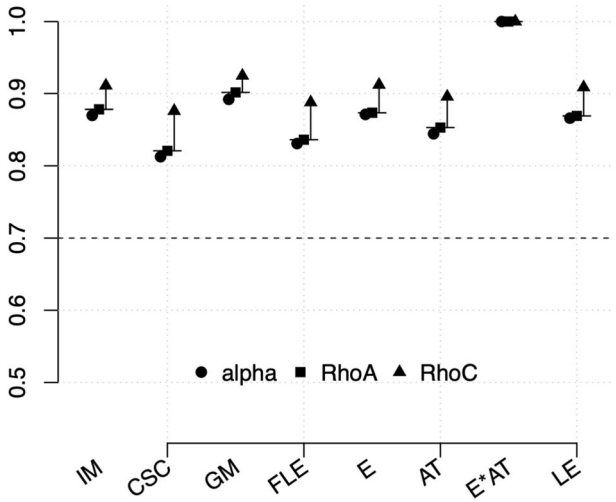

Fig. 2 Reliability charts regarding alpha, RhoA, and RhoC

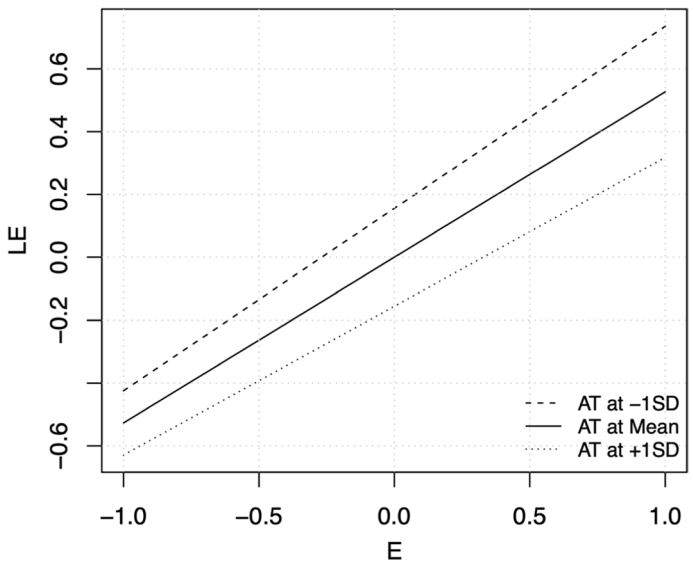

Fig. 3 Slope plot of the of the interaction effect E*AT on LE

- At an average level of AT, the "E → LE" relation is positive (BMR = 0.528) (see Table 5).
- While every increase in an SD unit of AT leads to a decrease of the "E → LE" relation by the size of E*AT (i.e., 0.527 + (− 0.052) = 0.475), every decrease in an SD unit of AT leads to an increase of the E → LE relation by the size of E*AT (i.e., 0.527—(− 0.052) = 0.579).
- According to the slope comparisons (see Fig. 3), the effect of E on LE is weaker at high levels of AT, while the effect of E on LE is stronger at lower levels of AT. Thus, AT negatively moderates the effect of E on LE.

Hypotheses-testing

The following recapitulations of the previous results provide evidence of testing the hypotheses.

- For the mediation structure involving IM, E, and LE, the indirect effect of IM on LE through E is significant, while the direct effect of IM on LE is insignificant. E exerts full mediation in the effects of IM on LE. These findings elicit the acceptance of H1 and H2 and the rejection of H3.
- For the mediation structure involving CSC, FLE, and E, the direct effect of CSC on E is significant, and the indirect effect of CSC on E through FLE is significant. FLE exerts complementary partial mediation in the effects of CSC on E. These findings elicit the acceptance of H4, H5, and H6.
- For the mediation structure involving GM, FLE, and E, the direct effect of GM on E is insignificant, and the indirect effect of GM on E is insignificant. FLE exerts no mediation in the effects of GM on E. These findings elicit the rejection of H7 and H8.
- For the moderation structure involving E, AT, and LE, AT negatively moderates the strength of the positive effect of E on LE. That finding elicits the acceptance of H9.

Discussion

This section presents the significance of the findings at the theoretical and empirical levels.

Full mediation of E in the effect of IM on LE in metaverse-based FLL

Acceptance of H1 and H2 indicates that E positively mediates the effect of IM on LE, while rejection of H3 demonstrates that the mediation of E accounts for the dominant part of the total effect in the mediation model "IM → E → LE". These findings are significant at the theoretical and empirical levels.

At the theoretical level, the full mediation of E in the effect of IM on LE extends the language learning model that emphasizes the cultivation of intrinsic motivation. Since intrinsic motivation reflects the autonomous control of minds to guide behaviors for goal attainments (Pintrich et al., 1991, p. 9; Xiao & Hew, 2023), internalization of language learning goals, behavioral regulations, and responses to external stimuli is assumed to contribute to FLL progress (Alamer et al., 2022). Notably, metaverse as one educational technology can provide augmentation/simulation experiences to transform original daily experiences into autonomy-cultivating experiences based on internal encouragement and stimulation of self-discipline (Kye et al., 2021; Liu & Hao, 2024). Since virtual settings created by metaverse require individuals' sense of belonging and immersion (Asiksoy, 2023), metaverse-based FLL requires engagement as the fundamental factor to be accustomed to the further-information-superimposed/synthesized physical contexts (Flores-Castaneda et al., 2024; Onu et al., 2023; Puncreobutr et al., 2022; Ryu et al., 2024; Shu & Gu, 2023). Thus, engagement bridges the positive effects of intrinsic motivation on learning in metaverse-based FLL.

The extension of the intrinsic-motivation-oriented language learning model elicits the following implications. In educational-technology-based FLL, motivating components conducive to immersive experiences, e.g., avatar, digital profiles, and rewarding

mechanics, are indispensable for individuals' spontaneous willingness to develop learning (Chen et al., 2024; Lashari et al., 2023) and fulfill substantial learning development through behavioral maintenance/change/(self-)control (Hwang et al., 2023; Jeon et al., 2024; Maghaydah et al., 2024; Yang, 2023). Since intrinsic motivation is compatible with engagement due to their emphases on spontaneity, autonomy, and involvement (Chiu, 2022; Liu & Hao, 2024) and indispensable for enhancement in language learning (Alamer et al., 2022), researchers can concentrate on the cultivations of intrinsic motivation for individuals' metaverse-based FLL progress. Besides, since competence, autonomy, and relatedness are the components conducive to engagement (Guo, 2021; Mohammad Hossein et al., 2022), educational technologies should provide various interactive opportunities that allow for voluntary and self-regulated participation in synergies of augmentation/simulation and inner world/external world (Xu et al., 2023), which contributes to innovative applications of metaverse in FFL contexts: augmented reality, lifelogging, mirror world, and virtual reality (Kye et al., 2021). These four metaverse application contexts enable individuals to subconsciously participate in communications associated with language proficiency enhancement (Celik & Baturay, 2024; H.-J. Chen, 2023a, 2023b; İbîlî et al., 2024; Kye et al., 2021).

The extension of the theoretical model also elicits advancements in understanding FLL. First, FLL is essentially an interactive process rather than a unilateral information delivery. Foreign language learners should actively participate in social interactions through meaningful communications to guarantee FLL progress. That understanding aligns with SCT which emphasizes social interaction as the indispensable step of language learning (Shadiev & Wang, 2022; Vygotsky, 1978) and reflects relatedness as one premise of engagement that facilitates FLL. Second, FLL proceeds with authentic language-use contexts as the condition of substantial progress. Authentic real-life environments reference the augmented or simulated learning circumstances that contribute to learning competence as the premise of engagement for learning development (H.-J. Chen, 2023a, 2023b; Fortuna et al., 2023; Qian et al., 2023). Third, for autonomous input and retrieval, FLL requires meaningful learning and cognitive pruning. This understanding is associated with meaningful mechanics of metaverse for autonomy as one premise of engagement for FLL enhancement (Chiu, 2022; İbîlî et al., 2024).

At the empirical level, the findings reflect that metaverse-based learning contains motivation-stimulating components by expanding the physical world (Harrington, 2024), encouraging participation in tailored networking (Dwivedi et al., 2022), providing real-time operations of interactive communications (İbîlî et al., 2024; Singh, 2024), and embodying individuals into avatars in instant simulated settings (H.-J. Chen, 2023a, 2023b; Tsappi et al., 2024). These approaches enhance individuals' subconscious willingness to use knowledge and make persistent progress, contributing to individuals' volitional immersion in interactive experiences, tailored commitments, and sustainable passion for academic work (Almulla, 2023; Aparicio et al., 2021; Chiu, 2022; Ghelichli et al., 2023; Lashari et al., 2023; Shakhmalova & Zotova, 2023). These statements reflect the effects of IM on E in metaverse-based FLL through the cultivation of autonomy, self-identification, and spontaneity (Celik & Baturay, 2024; Flores-Castaneda et al., 2024; Fortuna et al., 2023; Ryu et al., 2024). Apart from the facilitating effects of motivation on engagement in metaverse-based FLL, engagement can exert affective effects on

performative enhancement (Zhang & Huang, 2024). Since metaverse features interactive mechanics associated with attitudinal cultivations (Celik & Baturay, 2024), tailored interactivity encourages individuals to process received knowledge, output language, and overcome potential challenges in metaverse-based FLL (AlSaleem, 2023; Lee et al., 2022; Rashwan, 2023). Metaverse transforms from sheer stimuli-responses learning into internalization-oriented learning for better self-regulated and problem-solving (re) actions (Almulla, 2023; AlSaleem, 2023; Chen et al., 2024; Rashwan, 2023) (Almarzouqi et al., 2022; Qian et al., 2023). Augmentation/simulation mechanics of metaverse contribute to individuals' volitional (re)actions to knowledge input, sustainable immersion, systematic processing, and self-regulated output (Flores-Castaneda et al., 2024; Ryu et al., 2024), reflecting the process of cultivating individuals' affective states, i.e., intrinsic motivation and engagement for volitional immersion, and knowledge performance, i.e., active knowledge input and output for FLL progress. Thus, in metaverse-based FLL, learning performance is the explicit result of individuals' affective enhancements (Al-Adwan et al., 2023; Alamer et al., 2022; Panigrahi et al., 2021; Vezne et al., 2023).

In metaverse-based FLL, individuals experience superimposed or simulated language use through interactions with virtual-setting components/mechanics/rubrics and individuals represented as avatars. For instance, the symbolization of individuals' presence/behaviors in metaverse settings contributes to their engagement and progress (Chiu, 2022; Kye et al., 2021; Makransky & Mayer, 2022; Qian et al., 2023). These language use experiences align with the emphasis on social interaction for language proficiency, according to SCT (Shadiev & Wang, 2022; Vygotsky, 1978). Since interaction stimulates individuals' interest in participating in information exchanges and needs to enhance language, individuals foster need-oriented motivation for further development (AlSaleem, 2023; Chen et al., 2024; Lashari et al., 2023). As the cultivation of motivation proceeds from the external regulation to self-regulation stages (reflecting IM), individuals achieve spontaneity in involvement and participation (reflecting E) (Singh et al., 2022; Vezne et al., 2023). Individuals' spontaneous immersion in FLL experiences contributes to their perseverance in learning development and persistence enhancement in L2 performance (reflecting LE) (Alamer et al., 2022). Therefore, metaverse-based FLL can foster intrinsic motivation as a premise of engagement for progress in language proficiency. Engagement is an unneglectable factor in bridging the cultivation of intrinsic motivation and the progress in language performance in metaverse-based FLL.

Mediations of FLE in the effect of CSC/GM on E in metaverse-based FLL

Acceptance of H4-H6 indicates that FLE positively mediates the effect of CSC on E and that CSC can exert both a significant direct and indirect effect on E. In metaverse-based FLL, both "CSC → E" and "CSC → FLE → E" models are acceptable. Rejection of H7 and H8 indicates no significant relationship involving GM, FLE, and E in the mediation structure. These findings are significant at the theoretical and empirical levels.

At the theoretical level, complementary partial mediation of FLE in the effect of CSC on E and insignificant mediation of FLE in the effect of CSC on E extend the language learning model by highlighting the mixed effects of FLE in different mindsets. Since enjoyment belongs to individuals' positive attitudinal reaction to learning and contributes to sustainable learning persistence/passion (Li, 2023), FLE, as the perceived

enjoyment of using/learning foreign language (Mohammad Hosseini et al., 2022), can inspire individuals to strike a balance between perceived language-use skills and learning challenges (Jiang & Dewaele, 2019), conducive to engagement in autonomous learning based on self-confidence and sense of belonging (Guo, 2021; Mohammad Hossein et al., 2022). The facilitation degrees of FLE differ in different FLL contexts. When individuals prefer harmonious interactions, they can show more empathy as the crucial premise of positive affection and immersive involvement (Joe et al., 2017; Lee, 2020). In contrast, when individuals focus on attributing success, their excessive concentration on external factors leads to outperformance-oriented behaviors and ignorance of internal development, e.g., engagement, spontaneity, and internalization (Jiang & Dewaele, 2019). Thus, although FLE exerts overall facilitating effects on FLL, the effects of FLL are related to the individuals' mental orientation. Compared with an external-factor-oriented mindset, an interaction-oriented mindset can contribute to more significant effects of FLE on affective cultivations.

The extension of the FLE-effect-related model elicits the following implications. The effectiveness of FLL requires synergies of affective factors that contribute to positive psychological responses to learning (Mohammad Hosseini et al., 2022). Individuals' perceptions of curricular interactions foster their enjoyment and engagement in language learning/use (Lee, 2020; Li et al., 2021; Makransky & Mayer, 2022), while individuals' considerations of external factors would distract them from learning process per se and diminish their enjoyment (Jiang & Dewaele, 2019). Besides, in FLL employing educational technologies, enjoyment is an important factor in bridging the perception of the learning circumstances and self-perception of immersion (Singh et al., 2022; Venzne et al., 2023; Xiao & Hew, 2023). Enjoyment is the affective drive for cultivating engagement as the crucial factor conducive to FLL effectiveness (Almusharraf et al., 2023). Additionally, mental orientations do matter in affective cultivations in metaverse-based FLL. Social interaction per se enhances knowledge processing efficiency and productivity, which is associated with engagement in metaverse-based learning (Shadiev & Wang, 2022; Shakhmalova & Zotova, 2023; Schiller et al., 2024). In contrast, a success-attribution-oriented mindset is not directly related to engagement in metaverse-based FLL because metaverse provides virtual settings different from attributions in the physical world (Kye et al., 2021).

The extension of the theoretical model also elicits advancements in understanding FLL. First, affective conditions that matter in FLL require comprehensive rather than isolated interrelated cultivations. That understanding necessitates the importance of enjoyment in the activities provided by innovative digital technologies (Singh et al., 2022; Venzne et al., 2023; Xiao & Hew, 2023). Second, individuals' preference for curricular interactions contributes to FLL effectiveness. Metaverse featuring flexible interactions with materials/avatars through augmentation and stimulation meets the demand of individuals' interaction-oriented mindset for sustainable engagement in FLL (Kye et al., 2021; Puncreobutr et al., 2022). Third, FLL effectiveness is subject to individuals' mindsets that reflect individuals' orientations and needs. Excessive foci on external components would counterbalance the effects of innovative experiences on FLL (Jiang & Dewaele, 2019).

At the empirical level, the findings about the complementary partial mediation of FLE in the effect of CSC on E reflect that CSC emerges in affectively supportive learning contexts where individuals gain friendly and enjoyable experiences (reflecting FLE) and achieve engagement based on a sense of belonging, independence, and competence (reflecting E) (Mohammad Hosseini et al., 2022). Featuring secure and adaptive virtual learning circumstances, metaverse paves the path for cultivating CSC (Jovanović & Milosavljević, 2022; Ryu et al., 2022) by cultivating individuals' positive attitudes to interactive mechanics and communication-oriented activities designed for enhancing language proficiency (Li, 2023). Besides, the affective cultivation involving CSC, FLE, and E can enhance metaverse-based FLL performance. Supportive learning contexts that prompt friendly interactions and positive emotions can foster individuals' cognitive and performative enhancements: thought-activity repertory, self-discovery, and effective learning (Lee, 2020; Li et al., 2021; Li, 2023; Makransky & Mayer, 2022; Shadiev & Wang, 2022). Aiming to provide sustainable and volition-stimulating experiences, metaverse can exert persistent effects on affective cultivations associated with long-lasting learning performance extended to extracurricular situations (Abu-Salih, 2022; Al-Adwan et al., 2023; Almarzouqi et al., 2022; AlSaleem, 2023; Dayoub, 2022; Díaz et al., 2020; Qian et al., 2023). Therefore, CSC compatible with supportive metaverse-based FLL contexts can predict learning performance.

At the empirical level, the findings about the insignificant mediation of FLE in the effect of GM on E indicate potentially insignificant predictive effects of GM in FLL employing technology (Khajavy et al., 2022), including metaverse. In contrast to the discussion above that the external-factor-oriented mindset leads to deviations from language learning procedures per se (Jiang & Dewaele, 2019), the empirical discussion about the insignificant predictive effect is about its requirement of individuals' adaptability to novel interactive learning settings (Khajavy et al., 2022; Papi et al., 2019). Since metaverse can provide flexible circumstances tailored to practical needs (Qian et al., 2023; Ryu et al., 2022), metaverse-based FLL would contain changeable novel virtual settings. However, GM, as an enjoyment-related construct of individuals' perceptions of their language abilities/intelligence as an adaptable/increasable quality (Li, 2023), requires frequent adjustments and adaptations. Therefore, changeable virtual settings of metaverse-based FLL lead to unstable states of GM, reflecting the insignificant effects of GM on E and FLE.

Negative moderation of AT in the effect of E on LE in metaverse-based FLL

Acceptance of H9 indicates that AT negatively influences the strength of the positive relation between the exogenous factor E and the endogenous factor LE. That finding is significant at the theoretical and empirical levels.

At the theoretical level, negative moderation of AT in the effect of E on LE extends the language learning model about the FLL condition conducive to the solid facilitating effect of engagement. Since AT decreases the strength of the positive relation between E and LE in metaverse-based FLL, this negative influence of AT is consistent with the past study findings about the negative effect of AT on language performance by overemphasizing uncertainty in language learning (Chu et al., 2015; Moul et al., 2023). For

FLL contexts employing educational technologies, engagement is an essential premise of positive attitudinal/behavioral/performative states for learning achievement (Singh, 2024). However, ambiguous and uncertain materials would lead to disengagement and negatively influence the efficiency of processing information/interactions/materials for the learning process (Yu et al., 2022). Excessive ambiguity and uncertainty also impede processing conversational/interactive hints and adjusting social presence in learning circumstances, although these hints and presence sense are conducive to learning engagement (Aslan & Thompson, 2021; Jiang et al., 2023). Thus, an efficient association between engagement and FLL performance should be based on learning conditions with limited ambiguity and uncertainty in experiences and materials.

The extension of the FLL conditions beneficial for the efficient cultivation of engagement and learning outcomes elicits the following implication. In FLL conditions, AT is individuals' reaction to uncertainty that decreases engagement (Chu et al., 2015; Moul et al., 2023). That implication is also valid in FLL contexts employing educational technologies, necessitating the control of excessively uncertain experiences/mechanics/materials to guarantee engagement for learning achievement (Shakhmalova & Zotova, 2023). For metaverse-based FLL, ambiguous settings and individuals' perceived uncertainty would lead to distractions and disorientations (Harrington, 2024). Thus, metaverse-based FLL should proceed with explicit rubrics and mechanics to avoid aimless explorations that potentially result in deviation from educational purposes and disengagement from the settings.

The extension of the theoretical model also elicits advancements in understanding FLL. First, efficient FLL is based on limited ambiguity and uncertainty. Individuals can gain efficient information exchanges based on explicit rubrics/mechanics/instructions/presentations (Aslan & Thompson, 2021; Jiang et al., 2023). Second, integrating verbal information and non-verbal cues can decrease ambiguity to guarantee efficient FLL. Augmentations and simulations of the physical worlds contain visual and audial information to assist individuals' information processing for contextualized learning (Asiksoy, 2023; Han et al., 2023). Third, efficient FLL is associated with cultivating individuals' moderate tolerance and buoyancy to learning uncertainty and difficulty. Perseverance in learning adversities enables individuals to realize the inevitability of uncertainty and foster active problem-solving behaviors as the premise of efficient language learning (Aslan & Thompson, 2021; Moul et al., 2023).

At the empirical level, the finding reflects that AT is the affective factor that demotivates individuals to maintain the positive association between engagement and language learning performance (Chiu, 2022; Qian et al., 2023). In metaverse-based FLL, individuals' perception and excessive tolerance of adversities/difficulty/uncertainty decrease their volition to maintain immersion in language use conditions with potentially ambiguous information (Celik & Baturay, 2024; Kye et al., 2021; Yu et al., 2022). Debilitation in immersion results in individuals' passive or reluctant attitudes/behaviors of information processing and language enhancement (Chen, 2023a, 2023b; Paralkar & Knutson, 2023). Therefore, AT that debilitates E in language use would decrease the level at which E enhances LE.

Conclusion

This section presents major findings through the answers to the RQs, practical recommendations of metaverse use for FLL, and limitations for future directions.

Major findings

This study conducts PLS-SEM analyses to investigate how metaverse can facilitate FLL through the mediation/moderation of E, FLE, and AT in the effects involving IM, CSC, GM, and LE, associated with the conceptual model (see Fig. 1) eliciting RQ1-RQ3.

RQ1 is concerned with the influence of E. Acceptance of H1 and H2 confirms the significant indirect effect of IM on LE, while rejection of H3 confirms the insignificant direct effect of IM on LE. Therefore, the answer to RQ1 is that engagement facilitates metaverse-based foreign language learning by exerting full mediation in the effect of intrinsic motivation on language learning effectiveness.

RQ2 concentrates on the influence of FLE. Acceptance of H4-H6 confirms the significance and positivity of both the indirect effect of CSC on E through FLE and the direct effect of CSC on E. In contrast, rejection of H7 and H8 reveals the insignificance of both the indirect effect of GM on E through FLE and the direct effect of GM on E. Therefore, the answers to RQ2 are as follows. Foreign language enjoyment facilitates metaverse-based foreign language learning by exerting complementary partial mediation on the effect of classroom social climate on engagement, which positively influences language learning performance. By contrast, foreign language enjoyment does not significantly facilitate metaverse-based foreign language learning in the mediation model involving growth mindset as the exogenous factor and engagement as the endogenous factor.

RQ3 focuses on the influence of AT. Acceptance of H9 confirms the negative moderation of AT in the positive relation between E and LE. Therefore, the answer to RQ3 is that ambiguity tolerance influences metaverse-based foreign language learning by negatively moderating how engagement positively affects language learning performance.

The answers to RQ1-RQ3 elicit the main conclusion: in metaverse-based foreign language learning, engagement exerts fully positive mediation, foreign language use exerts partially positive mediation, and ambiguity tolerance exerts negative moderation in the positive effect of engagement on language learning effectiveness. Metaverse-based foreign language learning requires synergies of affective factors, i.e., intrinsic motivation, perceptions of classroom social climate, moderate degrees of ambiguity tolerance, and engagement, for language learning progress.

Practical recommendations

The mediation/moderation effects of E, FLE, and AT in metaverse-based FLL necessitate interactive, motivating, and friendly experiences for substantial and persistent progress in language mastery and performance. Since practical implementations of metaverse are indispensable attempts to offer situations for efficient FLL, the current study findings elicit the following practical recommendations for effective implantations of metaverse-based FLL.

Educators can emphasize the long-term habitual development of language learning rather than exclusive dependence on external rewards as the reinforcers of learning behaviors. Although metaverse experiences provide motivation-stimulating elements/

components/mechanics to enhance volitional learning behaviors, cultivating spontaneous and sustainable learning habits is conducive to persistent language learning progress. Since intrinsic motivation reflects the self-regulated state of learners' information processing and output, metaverse settings can explain why learners learn the language and the long-term benefits of learning this language. Thus, based on the reasons and benefits of learning as guides to continue learning, learners would exert voluntary efforts to proceed with learning, reflecting the positive association between IM and E for the learning process. Educators should also moderately monitor learners' use of metaverse technologies and give prompt interventions/guides to avoid technology misuse that leads to disengagement. Augmentation/simulation, i.e., virtualization of the original experiences, and inner-world/external-world-oriented mechanics, i.e., internal/external imitation of individuals' identities in the situations/control over the situations, enable educators to transform foreign language learning into metaverse contexts compatible with FLL: augmented reality, lifelogging, mirror world, and virtual reality.

Policymakers can concentrate on the substantial enjoyableness of the metaverse experiences for learners' positive attitudinal states for active (re)actions to interactive activities in virtual settings. When metaverse settings stimulate learners' genuine interest, learners gain positive perceptions of the technology-based presentations, confidence in technology use, and volition to perform behaviors in the technology-based experiences. Since social interaction is the indispensable premise of progress in language performance, the policymakers can allow the upgrading involvement of topics, components, and settings for metaverse mechanics to guarantee the adaptability to the contemporary learners' tastes and needs, reflecting the indispensable role of FLE in efficient learning. Immersive virtual storytelling-based settings are another interaction-oriented and interest-stimulating design for metaverse compatible with FLL that emphasizes meaningful information exchanges, reflecting the positive association between FLE and E in interactive settings. Notably, the designs of the interactive settings should consider the difficulty of learning materials and processes. Excessive difficulty in language learning materials would lead to learners' indifference to meanings and reluctance to proceed, reflecting the adverse effects of AT in the cultivation of E for FLL progress. Alterations of collaborative and competitive activities in metaverse experiences can foster their confidence in learning and raise their awareness of sustainable development.

Limitations and future directions

First, the investigation of metaverse-based FLL concentrates on higher education. Distinct educational levels would reflect different efficiencies of metaverse-based FLL implementations. Second, this study focuses on in-sample explanations of predictive effects of the affective factors. Humans' complex behaviors would lead to flexible and unstable relations between/among the constructs. Third, this study does not specifically define which foreign language(s) are regarded as the target foreign language. Different foreign languages might require different metaverse-based interactivities and show different efficiencies of metaverse applications. Fourth, since this study investigates the non-native language learning contexts, the limitation lies in the curricular experiences where students learn the target language. This study does not address the cultural

contexts as the factor of metaverse-based FLL. The relationships between/among the FLL variables are potentially subject to the cultural contexts of language learning.

These limitations elicit directions for future research. Future research could extend the coverage of education levels, e.g., elementary or secondary education, and language subskills, e.g., listening, speaking, reading, and writing, to investigate potentially different efficiencies of metaverse-based FLL. Besides, future research could consider the associations between the positivity and the stability of the mutual effects between/among the metaverse-based FLL constructs for more comprehensive explanations and detailed guides for implementations. Additionally, future research could address the foreign language learned in the metaverse-based FLL. Comparisons between/among metaverse-based FLL groups by different foreign languages are the approaches to demonstrating the efficiencies of metaverse in FLL more comprehensively. Furthermore, future investigation of the relationships among the metaverse-based FLL variables can be analyzable in different cultural contexts for university students' integrated purpose of learning use, eliciting more persuasive effects of metaverse on FLL considering cultural perceptions and consistency.

Supplementary Information

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Additional file 1

Additional file 2

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Authors contribution
QZ conceptualized the key constructs of the main idea, designed the methodology, conducted the research/investigation/analyses, wrote the original manuscript, and read/approved the final manuscript.

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