

Assessing Cognitive Extension in Extended Reality: Initial Evidence from a Confirmatory Factor Analysis

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Abstract

We report results from a confirmatory factor analysis of the Extended Reality Cognitive Extension Scale (XRCES), a multidimensional instrument designed to assess perceived cognitive extension in XR. Based on data collected from N=64 participants in a STEM mobile-AR learning context, we examine the scale's factor structure and provide empirical evidence for the underlying theoretical model to strengthen its application to XR research and practice.

CCS Concepts

• Human-centered computing → Mixed / augmented reality.

Keywords

Extended Reality, cognitive extension, XRCES, scale, evaluation

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1 Introduction

Cognitive assessment during immersion in extended reality (XR) environments [13] is key for effective engagement with virtual content, in particular for learning and training [8, 14, 15]. Prior studies have shown that STEM training can significantly reduce cognitive load when integrated in an augmented reality (AR) setup [3], working memory performance has been examined in virtual reality (VR) in relation to users' emotional states [5], and critical thinking has been shown to be positively influenced via VR simulations [18].

However, prior evaluations have typically employed generic instruments, such as the NASA TLX [6]. Recently, Braicov et al. [2] proposed the Extended Reality Cognitive Extension Scale (XRCES),



Figure 1: The mobile AR application used in our study to examine perceived cognitive extension in STEM learning.

a questionnaire designed to assess XR immersion from the lens of extended thinking [20], a paradigm that extends critical and computational thinking [21] to XR spaces. XRCES integrates the Cognitive Load Theory [19], Russell's Circumplex Model of Affect [17], Bloom's taxonomy [7], and the 4E cognition framework [12]. It comprises 18 items rated on a 5-point Likert scale, grouped into seven dimensions (Table 1); for example, *Perceptual Extension* refers to the capacity of an XR system to amplify user perception, such as observation of more details, structures, and spatial relationships [2].

However, the scale has not been examined yet through confirmatory factor analysis (CFA) [4], leaving its theoretical structure unverified. In this work, we provide the first confirmatory evaluation of XRCES, and extend Braicov et al.'s [2] original exploration with new empirical results to support application of XRCES in future research on perceived cognitive extension in XR environments.

2 Study

We conducted a study in the context of STEM learning to examine cognitive extension according to the seven dimensions of XRCES.

Sixty-four participants, 19 to 21 years old, all university students representative of the intended STEM learner population, volunteered for the study. By manipulating a physical cube, they engaged in learning about sunlight interactions with planetary surfaces via a mobile AR application designed with Merge EDU [10] (Figure 1).



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Table 1: Confirmatory Factor Analysis results for the Extended Reality Cognitive Extension Scale (XRCES) [2].

Item	Question (5-point Likert scale ranging from 1—very little to 5—very strong)	$\lambda^\ddagger$	R^2
1. Perceptual Extension ($\alpha=0.80$)			
Q1	To what extent did you perceive the virtual object as if it were real?	.79	.62
Q2	To what extent did you feel that the virtual object occupied a specific location in the physical space?	.89	.78
Q3	To what extent did the presence of the virtual object become more salient to you than the surrounding physical environment?	.73	.54
2. Memory Extension ($\alpha=0.70$)			
Q4	To what extent do you remember the virtual object as a 3D element that you explored, rather than as a 2D image?	.96	.92
Q5	To what extent did you feel that you naturally retained the information provided by the virtual object, without conscious memorization effort?	.65	.42
3. Attention Extension ($\alpha=0.74$)			
Q6 [†]	To what extent did you have to exert effort to remain focused on the virtual experience, while ignoring the surrounding physical environment?	.66	.44
Q7 [†]	To what extent did you have to exert effort to follow and understand the information provided through the virtual object?	.83	.69
Q8 [†]	To what extent did you have to exert effort to refocus your attention on the virtual object after interruptions?	.72	.52
4. Embodiment/Action Extension ($\alpha=0.82$)			
Q9	To what extent did you feel that the virtual object responded directly to your actions?	.82	.67
Q10	To what extent did you feel that the responses of the virtual object were smooth and predictable, without appearing artificial?	.84	.71
Q11	To what extent did you feel that you were interacting with the virtual object as if it were real?	.84	.71
5. Thinking Extension ($\alpha=0.77$)			
Q12	To what extent did you feel that you could solve the task by using visual cues from the virtual environment, without the need for prior mental calculations or deductions?	.86	.74
Q13	To what extent did you feel that the solutions you found were your own, even though you were guided by the application?	.94	.88
Q14	To what extent did you feel that you were able to make decisions more quickly than if you had worked with traditional paper-based materials?	.61	.37
6. Cognitive Integration Extension ($\alpha=0.82$)			
Q15	To what extent did the application clearly show you the steps required to solve the task?	.99	.99
Q16	To what extent did you feel that the application helped you detect and correct errors in real time?	.82	.67
7. Cognitive Sustainability Extension ($\alpha=0.64$)			
Q17	To what extent did you feel that the application made the task appear much easier than would have been without using the application?	.99	.99
Q18	To what extent did you feel that you learned new information through the virtual object?	.59	.35

[†]Ratings for this item are reverse-scored. [‡] λ denotes the standardized CFA loading (Std.all in lavaan [16]), and R^2 the proportion of variance explained by the latent factor. The loadings reported in this table were obtained from separate CFA models computed for each dimension ($N=64$).

The XRCES score averaged at 3.77 ($SD=0.48$), significantly above the scale's midpoint ($t_{(63)}=12.871$, $p<.001$, very large effect size $d=1.61$), revealing high perceived cognitive extension. Mean scores were moderate to high for *Perceptual Extension* ($M=3.85$, $SD=0.75$), *Memory Extension* ($M=3.82$, $SD=0.76$), *Thinking Extension* ($M=3.89$, $SD=0.73$); high for *Embodiment Extension* ($M=4.01$, $SD=0.80$), *Cognitive Integration* ($M=4.13$, $SD=0.71$), *Cognitive Sustainability* ($M=4.08$, $SD=0.78$); and low for *Attention Extension* ($M=2.61$, $SD=.89$).

Overall internal consistency indicated satisfactory reliability of the XRCES items to collectively measure perceived cognitive extension in XR (Cronbach's $\alpha=.84$, McDonald's $\omega=.89$). Per-dimension analysis revealed Cronbach's α values between .64 and .82, with six of the seven dimensions exceeding the .70 threshold, acceptable in early-stage research [9]; see Table 1 for the individual α values.

The overall Kaiser-Meyer-Olkin (KMO) measure was .83, indicating that data were suitable for confirmatory factor analysis, for which we used the lavaan R package [16]. A one-factor model, in which all 18 items loaded onto a single latent factor, was estimated using the Weighted Least Squares Mean and Variance-adjusted (WLSMV) estimator for ordinal variables. This initial model showed a poor fit ($\chi^2_{(135)}=510.235$, $p<.001$, CFI=0.777, RMSEA= 0.210); nevertheless, 11 of the 18 standardized loadings were above 0.70, showing strong relationships with the common factor. A seven-factor model, corresponding to the theoretical structure of XRCES [2], provided a better fit ($\chi^2_{(114)}=217.460$, $p<.001$, CFI=0.938, RMSEA=0.120), with

17 of the 18 loadings exceeding 0.70. These results support the multi-dimensional conceptualization of XRCES, although with the caveat that they should be interpreted with caution given our relatively small sample for CFA ($N=64$). Subsequently, we estimated separate one-factor models for each of the seven dimensions of XRCES. Table 1 reports the standardized factor loadings (λ) and explained variance (R^2) per item, obtained from the dimension-specific models. No loading fell below the 0.30 threshold, commonly recommended for item removal [1], indicating that all items contributed to the intended latent construct of their corresponding subscales.

3 Conclusion

We evaluated the proposed seven-dimensional theoretical structure of XRCES [2], a recently introduced scale for assessing perceived cognitive extension in XR. Our findings provide empirical support for its multidimensional model but, given our relatively small sample size ($N=64$), they constitute only initial evidence. Although all 18 items can be retained, some weaker loadings suggest that larger-scale studies [11] may be beneficial for further XRCES refinement.

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References

- [1] Godfred O. Boateng, Torsten B. Neilands, Edward A. Frongillo, Hugo R. Melgar-Quinonez, and Sera L. Young. 2018. Best Practices for Developing and Validating Scales for Health, Social, and Behavioral Research: A Primer. *Frontiers in Public Health* 6, Article 149 (June 2018), 18 pages. doi:10.3389/fpubh.2018.00149
- [2] Andrei Braicov, Tatiana Veverita, Ilona Popovici, Mihail Terenti, and Radu-Daniel Vatavu. 2026. XRCES: A Multidimensional Instrument for Assessing Cognitive Extension in Extended Reality. In *Proceedings of the IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering (MetroXRaine '26)*. IEEE, USA, 6 pages.
- [3] Andrei Braicov, Tatiana Veverita, Mihail Terenti, and Ivan Budanaev. 2026. Evaluating User Experience and Cognitive Load in AR-supported STEM Education. In *Proceedings of the 2026 International Conference on Development and Application Systems (DAS '26)*. IEEE, USA, 304–309. doi:10.1109/DAS69882.2026.11553320
- [4] Timothy A. Brown. 2015. *Confirmatory Factor Analysis for Applied Research* (2nd ed.). The Guilford Press, New York, NY, USA.
- [5] Daniel Gabana, Laurissa Tokarchuk, Emily Hannon, and Hatice Gunes. 2017. Effects of Valence and Arousal on Working Memory Performance in Virtual Reality Gaming. In *Proceedings of the 7th International Conference on Affective Computing and Intelligent Interaction (ACII '17)*. IEEE, USA, 36–41. doi:10.1109/ACII.2017.8273576
- [6] Sandra G. Hart and Lowell E. Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. In *Human Mental Workload*, Peter A. Hancock and Najmedin Meshkati (Eds.). Advances in Psychology, Vol. 52. North-Holland, Netherlands, 139–183. doi:10.1016/S0166-4115(08)62386-9
- [7] David R. Krathwohl. 2002. A Revision of Bloom's Taxonomy: An Overview. *Theory Into Practice* 41, 4 (2002), 212–218. doi:10.1207/s15430421tip4104_2
- [8] Lucie Kruse, Fariba Mostajeran, and Frank Steinicke. 2023. The Influence of Virtual Agent Visibility in Virtual Reality Cognitive Training. In *Proceedings of the 2023 ACM Symposium on Spatial User Interaction (SUI '23)*. ACM, New York, NY, USA, Article 14, 9 pages. doi:10.1145/3607822.3614526
- [9] Charles E. Lance, Marcus M. Butts, and Lawrence C. Michels. 2006. The Sources of Four Commonly Reported Cutoff Criteria: What Did They Really Say? *Organizational Research Methods* 9, 2 (2006), 202–220. doi:10.1177/1094428105284919
- [10] Merge EDU. 2026. Immersive Learning Platform. Retrieved August 2026 from <https://mergeedu.com>
- [11] Daniel J. Mundfrom, Dale G. Shaw, and Tian Lu Ke. 2005. Minimum Sample Size Recommendations for Conducting Factor Analyses. *International Journal of Testing* 5, 2 (2005), 159–168. doi:10.1207/s15327574ijt0502_4
- [12] Albert Newen, Shaun Gallagher, and Leon De Bruin. 2018. 4E Cognition: Historical Roots, Key Concepts, and Central Issues. In *The Oxford Handbook of 4E Cognition*, Albert Newen, Leon De Bruin, and Shaun Gallagher (Eds.). Oxford University Press, Oxford, UK, 3–16. doi:10.1093/oxfordhb/9780198735410.013.1
- [13] Philipp A. Rauschnabel, Reto Felix, Chris Hinsch, Hamza Shahab, and Florian Alt. 2022. What is XR? Towards a Framework for Augmented and Virtual Reality. *Computers in Human Behavior* 133 (2022), 107289. doi:10.1016/j.chb.2022.107289
- [14] Eric Redlinger, Bernhard Glas, and Yang Rong. 2021. Enhanced Cognitive Training using Virtual Reality: Examining a Memory Task Modified for Use in Virtual Environments. In *Proceedings of the 5th International Conference on Artificial Intelligence and Virtual Reality (AIVR '21)*. ACM, New York, NY, USA, 1–8. doi:10.1145/3480433.3480435
- [15] Lorcan Reidy, Dennis Chan, Charles Nduka, and Hatice Gunes. 2020. Facial Electromyography-based Adaptive Virtual Reality Gaming for Cognitive Training. In *Proceedings of the 2020 International Conference on Multimodal Interaction (ICMI '20)*. ACM, New York, NY, USA, 174–183. doi:10.1145/3382507.3418845
- [16] Yves Rosseel. 2012. lavaan: An R Package for Structural Equation Modeling. *Journal of Statistical Software* 48, 2 (2012), 1–36. doi:10.18637/jss.v048.i02
- [17] James A. Russell. 1980. A Circumplex Model of Affect. *Journal of Personality and Social Psychology* 39, 6 (1980), 1161–1178. doi:10.1037/h0077714
- [18] Diego Julian Santos Méndez, Margarita María Pineda Romero, and Dario José Delgado Quintero. 2025. Fostering Critical Thinking through Ethical Dilemmas in Virtual Reality: An Interactive Prototype with 3D Generative Agents. In *Proceedings of the 2025 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct '25)*. IEEE, USA, 869–870. doi:10.1109/ISMAR-Adjunct68609.2025.00231
- [19] John Sweller. 2011. Cognitive Load Theory. In *Psychology of Learning and Motivation*, Jose P. Mestre and Brian H. Ross (Eds.). Vol. 55. Academic Press, USA, 37–76. doi:10.1016/B978-0-12-387691-1.00002-8
- [20] Radu-Daniel Vatavu. 2026. Extended Reality Thinking: Why Interacting in XR Environments Calls for New Cognitive Skills. In *Proceedings of the Extended Abstracts of the CHI Conference on Human Factors in Computing Systems (CHI EA '26)*. ACM, New York, NY, USA, Article 286, 6 pages. doi:10.1145/3772363.3798484
- [21] Tatiana Veverita and Andrei Braicov. 2026. Computational Thinking and Critical Thinking in the Context of Extended Reality-based Learning Environments. In *Proceedings of the International Conference on Virtual Learning*. National Institute for Research & Development in Informatics, Bucharest, Romania, 481–502. doi:10.58503/icvl-v21y202641