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Interactive Multimedia Environment Intervention with Learning Anxiety and Metacognition as Achievement Predictors

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Abstract: Background: Interactive learning environments have emerged as transformative tools in education, enhancing engagement, academic performance, and addressing challenges like learning anxiety. This study examines the influence of multiple variables, including anxiety, internet usage for problem-solving, attitude towards a history course, metacognitive awareness, and interactive learning environments, on seventh-grade students' academic performance. Methods: Using the Exploration of Attitudes Towards History Scale (EDIS) scale to measure attitudes and the Metacognitive Awareness of Reading Strategies Inventory-Revised Two-Factor Version (MARSI-2fR) to assess metacognitive awareness, the study evaluated historical knowledge across three stages, namely pre-intervention, post-intervention, and a one-month-later retest. A comparative analysis was conducted between the control group and the intervention group. The statistical analyses involved the calculation of correlation coefficients, the implementation of general linear models, and the performance of Wilcoxon signed-rank tests. Results: The findings indicated that prior to the intervention, factors such as learning anxiety and the extratextual component of metacognition were statistically significant predictors of achievement. However, the aforementioned factors ceased to be statistically significant when the parameter of study strategies was incorporated into the statistical model. The impact of the interactive learning environment on students' achievement is highly statistically significant in terms of post-test scores, while the influence of all other predictors becomes insignificant. The retest confirmed the continued maintenance of the achieved results as evaluated following the intervention. Conclusions: The study confirms previous research demonstrating that interactive learning environments are an effective method of enhancing students' academic performance and reducing the negative impact of learning anxiety.

Keywords: anxiety; extratextual strategies; interactive learning environments; metacognition

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1. Introduction

The modern education system is transforming due to rapid advancements in science and technology, leading to the adoption of innovative technologies. The COVID-19 pandemic has significantly altered the educational process (Dumitru et al., 2024; Zhou et al., 2020), prompting novel methodological approaches, such as interactive learning environments (ILEs) (Malysheva et al., 2022). ILEs make learning more engaging and comprehensible, becoming an accessible teaching practice and attracting global research interest (Khlaif et al., 2021; Viner et al., 2020; Xue & Crompton, 2024).

Furthermore, the application of information and communications technology (ICT) in education is often subject-specific, varying with the content of each subject (Kyriakidis et al., 2024; Msafiri et al., 2023). In history education, it is essential to address the discipline's unique characteristics rather than treating technology as a generic tool (Tsivas, 2011). Students should move beyond merely using technology creatively; they must integrate technological literacy, curricular content, and skills to create meaningful historical experiences (Raave et al., 2024).

Digital tools are increasingly employed in history education for efficient access to resources, as many archives are now digitized and available online (Chouchene, 2019). The use of ICT in historical education enhances learning outcomes (Toktamysov et al., 2023). Advanced learning environments often focus on fostering historical literacy, thinking, consciousness, and reasoning, while also promoting students' metacognition and self-regulation (Poitras et al., 2012).

Understanding history requires acknowledging its spatial dimensions, making geographic information integration crucial in teaching (Martí-Henneberg, 2011). Interactive history learning environments effectively incorporate geographic information systems (GISs), which enable the efficient management, analysis, and presentation of spatial and other types of data (Lo et al., 2009). GISs can combine maps with verbal, visual, and auditory information, provided this integration minimizes cognitive overload (Asma & Dallel, 2020).

Using GISs with constructivist learning techniques in history education improves students' attitudes, especially for those who previously found the subject uninteresting when taught through traditional teacher-centered methods (Birsyada et al., 2023; Egiebor & Foster, 2019). These environments rely on constructivist and socio-cultural learning theories, moving away from behaviorist approaches designed for basic skills acquisition (Egiebor & Foster, 2019).

Anxiety is a common phenomenon in academic contexts, manifesting across various educational stages (Mastrothanasis et al., 2023). Referred to as "academic anxiety" or "learning anxiety", it is a psychological response triggered by stressors in academic settings (Cassady, 2022). This interplay of environmental and individual factors shapes students' perceptions of their capacity to handle challenges, influencing their evaluation of their ability to manage perceived pressure (Cassady, 2022).

Students frequently experience elevated anxiety during activities such as assignments with tight deadlines, impromptu exams, presentations, late arrival to campus, or failing to complete tasks (Berutu & Mutiawati, 2023). Excessive anxiety negatively impacts mental health and classroom performance (Faisal et al., 2022; Mastrothanasis et al., 2023). Often arising from negative past experiences, it fosters worry, failure expectations, risk aversion, and task avoidance, while increasing cognitive load by consuming attentional resources (Berutu & Mutiawati, 2023; Wells, 2006; Zinbarg et al., 2022). Elevated anxiety is strongly linked to poor academic outcomes, driven by perceived incompetence that undermines confidence in cognitive abilities (Cassady, 2022). Various forms of anxiety—test, mathematics, and traits—affect different aspects of academic performance (Núñez-Peña & Bono, 2019).

Metacognition (i.e., thinking about thinking) plays a dual role in anxiety. Maladaptive metacognitive beliefs often increase anxiety (Wells, 2019), while high metacognitive awareness may heighten recognition of worries, potentially exacerbating anxiety symptoms (Ryum et al., 2017). Conversely, employing metacognitive strategies can alleviate these symptoms by enabling students to control tension and improve academic outcomes (Koulianou et al., 2019; Mastrothanasis et al., 2018a, 2018b; A. Mavrogianni et al., 2023b; Zepeda & Nokes-Malach, 2021). On the contrary, anxiety can deplete cognitive resources, impairing access to metacognitive knowledge and strategies (Huntley et al., 2022).

Metacognition helps students understand their learning processes and emotional states, promoting structured approaches to learning and stress management (Zepeda & Nokes-Malach, 2021). Effective metacognitive strategies allow students to address challenges more efficiently, enhancing both academic performance and emotional well-being (Ugalde et al., 2021). Wang and Macintyre (2021) suggest that metacognition can interact with the impact of anxious thoughts during learning. Strengthening metacognitive strategies, such as planning or self-monitoring during language learning, can help mitigate these effects, improving both well-being and achievement (Stanton et al., 2021). For example, strategies like rehearsing presentations or reflecting on study approaches enable students to manage learning effectively, thus reducing anxiety's influence on performance (Fooladvand, 2017).

Thus, metacognition is an ambivalent phenomenon, encompassing both positive and negative dimensions. While heightened metacognitive awareness may elevate anxiety by increasing cognitive load, it simultaneously provides tools for overcoming challenges and reducing anxiety (Silaj et al., 2021). Striking a balance between these aspects allows students to harness metacognitive knowledge, optimizing both learning outcomes and emotional resilience.

Given the above, our study aims to examine whether the instruction through an interactive learning environment based on the ESRI GIS Story Map Journal platform (ESRI Inc., Redlands, CA, USA) has a positive effect on history course performance. The present study sets out to explore the potential of interactive multimedia environments to intervene in cases of learning anxiety, with a view of elucidating the role of metacognition in the prediction of academic achievement. In addition, we will examine how factors such as anxiety, internet use for problem-solving, students' attitudes towards the history course, and metacognitive awareness affect students' performance.

We formulated the following hypotheses:

H1. *Interactive learning would play a critical role in enhancing students' academic performance in the history course.*

H2. *The negative impact of learning anxiety in cognitive processes and performance would be affected when specific study strategies and interactive learning environments are introduced.*

H3. *Metacognitive practices would play a key role in academic performance, with extratextual components serving as stronger predictors of achievement by fostering deeper understanding and engagement than text-oriented components.*

H4. *The students' attitude towards history as measured by the Exploration of Attitudes Towards History Scale (EDIS) would enhance metacognitive processes and performance.*

2. Materials and Methods

2.1. Participants and Procedure

All the participants (n = 54; 51.9% boys and 48.1% girls) were 15 years old. The two class groups were randomly selected out of eight in the A General Lyceum class of the 2nd General High School of Heraklion, located in Crete, Greece. A second random selection was conducted to assign one section to the intervention group and the other to the control group. Participation was secured after obtaining consent from parents or guardians. The intervention group (n = 27) received experimental interactive instruction using the Geo-History Interactive Learning Environment on the ESRI GIS Story Map Journal platform, while the control group (n = 27) received traditional teaching methods from their teacher. The participants represented a typical classroom sample, characterized by the usual diversity in students' abilities, skills, and performance levels (Bryman, 2016). None of the students had diagnosed learning difficulties, while all of them (100%) were native Greek speakers. Their residence was placed mainly in the city (51 students, 94.4%), while 2 (3.7%) lived in the suburbs and 1 (1.9%) in a village.

The sample size of this study was determined by the practical constraints of conducting an educational intervention in a real-life school setting. The sample size of 27 participants per group exceeds the recommended sample size calculated using a power analysis. Based on the sample size calculation, a minimum of 23 participants per group would provide 80% power to detect a difference of 2 units between group means, with a pooled standard deviation of 1.8 units, a significance level of 5%, and a superiority margin of 0.5 units. The chosen sample size ensures robust statistical power while accounting for potential variability in the study population and adhering to the study's methodological requirements.

2.2. Instruments

To investigate the attitude towards history and the metacognitive awareness of the students, two psychometric tools' data were collected using two inventories both in the form of a 5-point Likert-type scale, namely the Exploration of Attitudes Towards History Scale (EDIS) (Mavrogianni et al., 2021) and the Metacognitive Awareness of Reading Strategies Inventory-Revised Two-Factor Version (MARSI-2fR) (Mavrogianni et al., 2023c). Both inventories have been subjected to successful reliability, validity, and psychometric evaluation tests and shown to have very good properties for use in the Greek student population.

The EDIS scale is a psychometric self-referential instrument (Mavrogianni et al., 2021) comprising 11 statements in the final version of the scale (Cronbach's α = 0.804) in 4 subscales/factors. Factor 1 (3 items, Cronbach's α = 0.793) is related to the "effect of the use of information and communication technologies (ICTs) on attitude towards history"; factor 2 (3 items, Cronbach's α = 0.776) to the "study strategies" of the history course; factor 3 (3 items, Cronbach's α = 0.761) to the "broad attitude" towards the subject of history; and factor 4 (2 items, Cronbach's α = 0.738) to the "effect of the use of a historical map". The scores on the scale and its subscales can be extracted as the average values of the statements that contribute to each factor.

The MARSI-2fR scale was derived by weighting the original three-subscale MARSI scale of Mokhtari and Reichard (2002) on a Greek student population (n = 1.263) comprising students from all levels of secondary education, including middle school and high school, general, and vocational. It is a psychometric instrument designed to investigate metacognitive awareness by recording the use of reading strategies.

A weighting of the scale for the Greek population (Mavrogianni et al., 2023a) yielded an abbreviated, valid, reliable, and assessable two-factor structure, involving the metacognitive awareness MARSI-2fR scale (Cronbach's α = 0.737) comprised by text-oriented reading strategies (Cronbach's α = 0.767) and extratextual reading strategies (Cronbach's α = 0.693) (Mavrogianni et al., 2023c). This bifactorial structure elucidates the study habits of Greek secondary school students, reflecting the characteristics of the exam-centered Greek educational system and the use of a distinct textbook for each subject (Anagnostopoulou et al., 2013; Katsarou, 2009). The mean score for each structure of the MARSI-2fR scale is calculated by dividing the score by the number of items included. The first subscale includes five items, the second subscale includes three items, and the whole scale includes eight items. A categorization of mean scores on any of these structures may prove beneficial in understanding how students' reading habits align with these scores. The mean scores were categorized in accordance with the criteria set forth by Mokhtari and Reichard (2002) into three predefined levels of utilization of reading strategies as follows: low ($\leq$2.4), moderate (2.5 to 3.4), and high ($\geq$3.5).

2.3. Data Variables

The dependent variable is the measurement of the educational achievement (academic performance for historical knowledge) considered in three phases, which are pre-intervention, post-intervention, and retesting one month later, either for the traditional (control group) or the interactive (intervention group) approach. In all instances, the performance was computed by employing tests with closed-ended questions.

The independent variables—possible predictors of achievement—were interactive learning environments, learning anxiety (history memorization anxiety), internet usage for problem-solving, attitude towards the history course, metacognitive awareness, study strategies scores, the text-oriented component of metacognition, and the extratextual-oriented component of metacognition. The values for all these variables were taken for all three stages of the study, prior to the intervention, immediately after the intervention, and a retest one month later.

The independent variables were defined and measured as follows: the interactive learning environment was coded as a binary variable (0 for the control group, 1 for the intervention group). Learning anxiety (assessed through a self-referential 5-point Likert-type scale) and internet usage for problem-solving (also measured with a self-referential 5-point Likert-type scale) had scores ranging from 1 to 5. Attitude towards the history course was evaluated using the EDIS scale (11 items; total score range 11 to 55). Metacognitive awareness was measured via the MARSI-2fR scale (8 items; total score range 8 to 40). The study strategies score was derived from the second factor of the EDIS scale (3 items; total score range 3 to 15). Metacognition was further divided into two components, the text-oriented component (5 items from the first factor of the MARSI-2fR scale; total score range 5 to 25) and the extratextual-oriented component (3 items from the second factor of the MARSI-2fR scale; total score range 3 to 15). It is notable that in this approach, none of the factors under investigation are of a socio-economic type; rather, they are exclusively educational factors because power analysis typically centers on variables that directly align with the study's primary research objectives or hypotheses.

2.4. Ethical Considerations

The research protocol was approved as an experimental field study by the Research Ethics Committee of the University of Crete (2/2018/13-03-2018). The Ministry of Education and Culture also approved the conduct of the study with prot. no. 89964/D2 of 01-06-2018.

2.5. Statistical Analysis

For the data analysis, we used SPSS version 26 software (IBM Corp., Armonk, NY, USA). Comparisons were made between the control group and the intervention group of equal size ($n = 27$). Descriptive statistics were applied to summarize the key characteristics of both groups, including means, standard deviations, and other summary measures, providing an initial overview of the data. The normality of subgroups as well as of standardized residuals was tested through the Shapiro–Wilk test. We used nonparametric tests in cases where the normality assumption was violated (see, for example, Linardakis, 2023). Mann–Whitney nonparametric tests were used to test whether the median values of the groups differ significantly. A general linear model was employed to examine pre- and post-performance and how these are related to a set of independent variables and to compare changes between the control and intervention groups. The Wilcoxon signed-rank test was used to assess statistically significant differences within groups between two time points.

3. Results

Table 1 provides descriptive statistics across both the control and intervention groups. The mean and standard deviation values are presented for pre-intervention achievement, post-intervention achievement, learning anxiety, study strategies, and the metacognitive components (text-oriented and extratextual). These statistics offer an overview of the data distribution and highlight key differences between the groups, particularly in post-intervention achievement, where the intervention group exhibited significantly higher scores with minimal variability.

Table 1. Descriptive statistics of the variables of the study, Shapiro–Wilk tests of normality, and Mann–Whitney tests.

Variables	Control Group			Intervention Group		Shapiro–Wilk *p*	Mann–Whitney (*p*)
	M	Std	Shapiro–Wilk *p*	M	Std		
Pre-intervention achievement	7.000	2.717	0.282	7.667	3.942	0.296	320.0 (0.439)
Post-intervention achievement	8.556	2.650	0.404	14.889	0.320	<0.001	0 (<0.001)
Learning anxiety	2.520	1.156	0.018	3.070	1.299	0.016	275.5 (0.113)
Study strategies	10.926	1.708	0.020	11.000	2.801	<0.001	307.5 (0.321)
Text-oriented metacognition	18.889	3.755	0.046	21.185	2.497	0.157	225.5 (0.015)
Extratextual metacognition	8.000	2.882	0.261	8.481	2.833	0.045	284.5 (0.163)

Note. M = Mean; Std = Standard Deviation.

Table 1 also provides the results of the Shapiro–Wilk tests of normality. In all cases but the pre-intervention achievement, normality was violated for at least one of the two groups. To test whether the median values of the groups for the variables differed significantly, we used Mann–Whitney nonparametric tests.

The results of the Mann–Whitney tests reveal several important findings. First, no significant differences were observed between the control and intervention groups for pre-intervention achievement ($p = 0.439$), learning anxiety ($p = 0.113$), study strategies ($p = 0.321$), and the extratextual component of metacognition ($p = 0.163$). However, a highly significant difference was found in post-intervention achievement ($p < 0.001$), indicating that the intervention group performed substantially better than the control group. Additionally, the text-oriented component of metacognition showed a significant difference between the groups ($p = 0.015$), suggesting that the levels of the two groups were different in this aspect of metacognitive processes prior to the intervention.

To test the effect of learning anxiety, extratextual and text-oriented components of metacognition and study strategies, and the group of students (control/intervention) on pre- and post-intervention achievement, we used general linear models. The independent variables "internet usage for problem-solving", "attitude towards the History course", and "metacognitive awareness" were tested and removed through a backward elimination procedure of finding the parsimonious models, as they had no statistically significant effects on academic performance (achievement). Thus, we focused on the rest of the variables for both the control and the intervention groups (variable: interactive learning environments), which included learning anxiety (history memorization anxiety), study strategies scores, the text-oriented component of metacognition, and the extratextual-oriented component of metacognition. The results are given in Table 2. Model 1a (explanatory variable "study strategies" not included) shows that in pre-intervention achievement, learning anxiety and the extratextual component of metacognition are statistically significant predictors but become weakly statistically significant when the parameter of study strategies is included in the statistical model (Model 2a), showing the importance of the "study strategies" parameter on the pre-intervention achievement. In Model 1a, learning anxiety is a highly statistically significant predictor of pre-intervention achievement, with a negative effect ($b = -0.933$) and a high partial eta squared. Moreover, in Model 1a, the extratextual-oriented component of metacognition is a highly statistically significant predictor of pre-intervention achievement, with a positive effect ($b = 0.486$) and a high partial eta squared, which also has no significant effect on post-intervention achievement. The tests on the standardized residuals of Models 1a and 2a showed that the hypotheses of normality of the general linear models were not rejected. Both Shapiro–Wilk tests showed p-values > 0.05.

Table 2. Parameter estimates of the general linear models. Dependent variable achievement.

Variable	Parameter	b	t	p	η^2
	Models 1a and 1b				
a. Pre-intervention achievement	Learning anxiety	−0.933	−2.814	0.007	0.137
	Extratextual metacognition	0.486	3.358	0.002	0.184
	Intervention group *	0.717	0.862	0.393	0.015
b. Post-intervention achievement	Learning anxiety	0.069	0.317	0.753	0.002
	Extratextual metacognition	0.024	0.250	0.804	0.001
	Intervention group *	6.272	11.525	<0.001	0.727
	Models 2a and 2b				
a. Pre-intervention achievement	Learning anxiety	−0.610	−1.850	0.070	0.065
	Extratextual metacognition	0.288	1.895	0.064	0.068
	Study strategies	0.556	2.875	0.006	0.144
	Intervention group *	0.687	0.884	0.381	0.016
b. Post-intervention achievement	Learning anxiety	0.146	0.632	0.530	0.008
	Extratextual metacognition	−0.024	−0.223	0.824	0.001
	Study strategies	0.133	0.980	0.332	0.019
	Intervention group *	6.265	11.506	<0.001	0.730

Note. * Baseline category: control group.

The mean difference between the control and intervention group is not statistically significant for pre-intervention achievement, whereas it becomes the only highly statistically significant explanatory factor for post-intervention achievement (Models 1b and 2b), setting learning anxiety and the extratextual-oriented component of metacognition as non-significant. That is, on post-test scores, the effect of the interactive learning environment on students' achievement is strongly statistically significant, whereas the effect of all other predictors becomes non-significant. However, it should be noted that the hypothesis of normality of the standardized residuals of Models 1b and 2b was rejected (Shapiro–Wilk $ps < 0.001$). As a result, any conclusions drawn from these parameters should not be considered valid. This discrepancy arises due to the performance of the experimental group in the post-test, where all students achieved perfect scores, a phenomenon commonly referred to as the ceiling effect. This outcome violates the normality assumption, rendering the statistical inferences based on these models unreliable.

The only meaningful insight to be extracted from Models 1b and 2b is the observation that the students in the experimental group excelled uniformly, achieving top scores in the post-test. This finding underscores the effectiveness of the intervention within this specific context but also highlights the limitations of the models in providing a broader interpretative framework due to the distortion caused by the ceiling effect. Further analysis should consider alternative approaches or models that account for such distributional anomalies to ensure the robustness and reliability of the conclusions.

The text-oriented component of metacognition was also included in Models 1 and 2 but was removed as a non-statistically significant variable in the process of finding the optimal/parsimonious statistical model.

Regarding the maintenance of achievement four weeks after the end of the intervention (retest), we tested if there was a significant difference in the mean achievement between post- and retest values. The Shapiro–Wilk tests of normality on the achievement's differences showed that normality is violated for the scores of the intervention group. For this reason, we used the nonparametric Wilcoxon signed-rank test to test if there are significant differences in the median values between post-test and retest. The results are given in Table 3.

Table 3. Descriptive statistics on achievements of post-test and retest.

Group	*n*	Post-Test		Retest		Wilcoxon Signed-Rank Test		Shapiro–Wilk	
		Mean	Std	Mean	Std	z	*p*	Value (df)	*p*
Control	27	8.556	2.650	8.074	2.973	−0.678	0.498	0.966 (27)	0.494
Intervention	27	14.889	0.320	14.704	0.669	−1.667	0.096	0.630 (27)	<0.001

4. Discussion

The intervention was found to be highly effective (H1), as the use of the interactive learning environment ensured that all the students involved were able to perform with excellence, thereby corroborating the findings of research on the strong effect of type on performance. The intervention group's significantly higher post-intervention achievement scores—observed with minimal variability—demonstrate the capacity of ILEs to facilitate uniform academic excellence across students. These results are in line with research indicating that ILEs positively impact student performance, showing that these environments can foster better cognitive outcomes by providing dynamic, engaging, and interactive learning experiences that promote active participation and deeper engagement with the content (El-Sabagh, 2021; Mavrogianni et al., 2023a).

Concerning learning anxiety and metacognition prior to the intervention (H2), the study found that both of these variables had a significant impact on pre-intervention achievement. Specifically, learning anxiety appeared to negatively affect student performance, as supported by prior research on anxiety's detrimental effects on cognitive functioning (Lai et al., 2015; Núñez-Peña & Bono, 2019). Students experiencing anxiety may find the academic content to be too daunting and overwhelming, leading them to experience worry and apprehension. As a result, anxiety may undermine their sense of competence, reducing their confidence in completing tasks (Wells, 2006). Additionally, anxiety can impair cognitive processes necessary for academic tasks, including memory and attention (Cassady, 2022). As anxiety is intensified by unsatisfactory outcomes, students may employ maladaptive coping strategies, including the avoidance of certain academic tasks (Cassady, 2022; Mastrothanasis et al., 2023).

Regarding H3, the extratextual component of metacognition exhibited a positive influence by encouraging divergence from rote learning and deeper engagement with supporting materials, while the text-oriented component was found to be a weak predictor of performance. This finding supports the notion that metacognitive strategies can help anxious students overcome automatic negative thoughts and improve cognitive performance (Wang & Macintyre, 2021). By promoting deeper reflection on how they learn, students may better regulate their emotions and cognitive resources, ultimately enhancing academic outcomes.

A notable finding was that the adoption of study strategies (as measured by factor 2 of the EDIS scale), which moderate the effect of learning anxiety and the extratextual component of metacognition on performance (H4). Therefore, further research could explore by experimental design how the cultivation of these specific study strategies might potentially reduce the effect of anxiety on student achievement. The study suggests that fostering metacognitive awareness and encouraging the use of effective study strategies—such as rehearsing presentations or reviewing for exams—can reduce the detrimental impact of anxiety and improve overall achievement (Fooladvand, 2017).

From a practical level, the results underscore the efficacy of ILEs in fostering enhanced student achievement while simultaneously reducing the anxiety commonly associated with academic challenges. In order to facilitate the integration of the aforementioned findings into pedagogical practices, the following specific strategies could be employed: the design of interactive and collaborative tasks within ILEs (Blannin & Kung, 2023) and the encouragement of student-led exploration of topics (French et al., 2020). In addition, teachers might provide structured guidance on effective study techniques, adapted to both the content and the age group of the students concerned. Therefore, these findings provide a valuable basis for teachers and policymakers to devise educational interventions that cater to the diverse needs of students, thereby cultivating a more inclusive and supportive learning environment in which all students feel adequately prepared to thrive (Molina Roldán et al., 2021).

However, this study is not without limitations. Despite the random selection of participants, conducting the research within a single school introduces potential biases due to the specific school environment, teaching quality, or institutional culture. Given the homogeneity of the sample in this study (15-year-old students from a single school), future research should explore the performance of ILEs with more heterogeneous populations. It is imperative to acknowledge the potential for variability in outcomes across diverse age groups, educational levels, and cultural contexts (Müller et al., 2024). For instance, younger students may require more scaffolded support within ILEs, whereas older students might benefit from greater autonomy and self-directed tasks. Furthermore, cultural contexts have the capacity to influence the way students engage with interactive tools and historical narratives (Reiser, 2018). Consequently, adaptations must be made to ensure inclusivity and relevance.

Additionally, the intervention was conducted in a context focused solely on primary and secondary school students. Future studies could investigate the use of interactive learning environments (ILEs) in a broader spectrum, including students from pedagogical and teaching schools, who will themselves teach history to younger students. By targeting this demographic, researchers could evaluate the ILE's potential in preparing future educators with advanced teaching strategies, enhancing their ability to provide multisensory learning experiences that cater to diverse learner needs.

Alternative statistical models should be explored to address the ceiling effect observed in the intervention group, which could affect the generalizability of the conclusions drawn from this study. Incorporating models that account for such anomalies may yield more nuanced insights into how ILEs impact learning outcomes across a broader range of achievement levels (Huntington et al., 2023). Furthermore, the current ILE could be restructured and refined using various AI applications to enhance accessibility and personalization. Future iterations could emphasize multidevice compatibility, particularly focusing on mobile devices for stronger interaction and more seamless integration into students' everyday learning practices. The incorporation of adaptive learning technologies could enable tailored interventions, providing personalized learning paths and activities aligned with individual user needs.

Finally, expanding the scope of the ILE to include diverse historical contexts beyond the specific period studied here would be valuable. Broader content coverage would allow researchers to assess whether the benefits observed in this study are universally applicable or context-specific. This could include evaluating how multisensory approaches and AI-driven tools perform in fostering historical literacy and engagement across different cultures and educational systems.

5. Conclusions

The findings from this study underscore the effectiveness of interactive learning environments (ILEs) in fostering historical literacy, alleviating learning anxiety, and enhancing metacognitive engagement. By addressing the unique challenges of history education, this research provides new insights into how ILEs can optimize both cognitive and emotional outcomes for students. The results suggest that when carefully designed, ILEs can not only improve academic performance but also enhance students' metacognitive awareness and reduce anxiety, making them valuable tools for history educators. Furthermore, these findings highlight the importance of tailoring educational interventions to the specific needs of learners and integrating innovative approaches to foster engagement and inclusivity in diverse learning contexts.

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