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Factor Structure Analysis and Validation of a Virtual Media Literacy Education Model in Cyberspace for Teaching Biology: A Structural Equation Modeling Approach

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A B S T R A C T

Purpose: The objective of this study was to design and validate a virtual education model for media literacy in cyberspace aimed at teaching biology.

Methods and Materials: This research employed a quantitative approach using Structural Equation Modeling (SEM) and Confirmatory Factor Analysis (CFA). After extracting the initial dimensions and components of the model through qualitative studies and a review of the literature, a researcher-developed questionnaire was constructed and administered to a sample of 217 biology teachers in Wasit Province, Iraq.

Findings: The results of a three-order confirmatory factor analysis indicated that the designed model demonstrated a good fit (SRMR = 0.081; GOF = 0.621) and comprised three main dimensions: instructional, supportive, and technological. The instructional dimension, with a factor loading of 0.981, was identified as the most significant factor in virtual media literacy education. Reliability indices (Cronbach's alpha, composite reliability) and convergent and discriminant validity indicators (AVE, HTMT, Fornell and Larcker) also showed acceptable values. The findings revealed that the components of "continuous assessment and feedback," "interactive learning," and "gamification in online education" had the greatest impact on the success of the model.

Conclusion: Based on the results, the proposed model can serve as an effective framework for designing virtual instruction grounded in media literacy, and it can be utilized by teachers, curriculum planners, and educational policymakers.

Keywords: *virtual education, media literacy, biology, cyberspace, confirmatory factor analysis, structural equation modeling.*

1. Introduction

The rapid evolution of digital technologies and their pervasive integration into education systems worldwide have transformed the nature of teaching and learning, particularly in the sciences. In this context, biology education—a field traditionally reliant on physical laboratories and experiential learning—has encountered significant challenges and opportunities with the shift to virtual platforms. As a response to these transformations, the development of educational models that incorporate media literacy in virtual environments has gained critical importance, especially for enabling meaningful engagement, inquiry-based learning, and critical thinking in online biology instruction (Navarro et al., 2024).

Media literacy, as defined by international frameworks, refers to the ability to access, analyze, evaluate, create, and act using all forms of communication, including digital and multimedia content (Unesco, 2023a). In virtual education settings, particularly those that emerged and expanded during the COVID-19 pandemic, media literacy is no longer an optional competency but a foundational element for both learners and educators (Najafi Nejad, 2020). In biology education, this necessity becomes more pronounced, as the subject requires not only content comprehension but also the interpretation of scientific images, simulations, virtual experiments, and data visualizations—skills that are closely aligned with media literacy capabilities (Dewi, 2023; Navarro et al., 2024).

The implementation of virtual education in biology teaching requires a structured pedagogical foundation that integrates technological, instructional, and support dimensions. This integration is central to models such as Technological Pedagogical Content Knowledge (TPACK), which emphasizes the balanced and dynamic interaction of content knowledge, pedagogy, and technology in teaching (Mishra & Koehler, 2020). Within this framework, media literacy operates as both a transversal skill and a pedagogical enabler that enhances learner autonomy, fosters critical reflection, and supports knowledge construction (Hobbs, 2017; Potter, 2018).

Virtual education has also been reshaped by conceptual innovations such as the SAMR model (Substitution, Augmentation, Modification, Redefinition), which classifies levels of technology integration in education. Media literacy education in cyberspace ideally operates at the levels of modification and redefinition, where technology fundamentally alters the learning experience and allows students to engage in authentic, inquiry-based, and participatory learning environments (Puentedura, 2020). This is particularly relevant for biology teachers who must design activities that replicate or even transcend the capabilities of traditional labs.

Despite these theoretical advancements, empirical evidence suggests that many teachers lack the necessary training and confidence to integrate media literacy into their virtual instruction effectively. For instance, studies indicate gaps in teachers' understanding of digital resource evaluation, ethical content use, and online engagement strategies (Korona, 2024; Lee et al., 2023). These limitations are often compounded by structural inequities in educational access, digital infrastructure, and support systems, particularly in developing contexts (Shariati et al., 2024; Sheikhabadi et al., 2024).

Accordingly, the present study aims to develop and validate a conceptual model of virtual education for teaching biology based on media literacy principles. Drawing on theoretical foundations and empirical insights, this model is structured around three interdependent dimensions: instructional design, technological infrastructure, and supportive mechanisms. Each dimension encompasses a range of components—including interactive learning, content creation, gamification, assessment feedback, and instructional support—that collectively address the cognitive, emotional, and technological needs of learners (Davarpanah et al., 2023; Ebrahim Aziz Al-Zarji et al., 2024).

Instructional design, as the core dimension, is informed by the principles of cognitive load theory and multimedia learning, which stress the importance of managing learners' cognitive capacities through well-structured, visually-supported, and meaningful instruction (Abdi, 2019; Salari & Amirteimoori, 2017). In this regard, media literacy empowers learners to decode scientific content, participate in simulations, and engage with digital texts, thereby deepening their conceptual understanding (Dewi, 2023). Moreover, gamification and interactive elements have been shown to increase learner engagement and retention, particularly in online environments where motivational challenges are more pronounced (Binh, 2020; Means et al., 2014).

The technological dimension of the model involves the digital tools and platforms used to facilitate biology instruction. This includes the integration of learning management systems (LMS), video conferencing applications, interactive simulations, and cloud-based

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collaboration tools. However, mere access to technology is insufficient unless accompanied by media literacy skills that enable both teachers and students to use these tools effectively and critically (Ghahremani & Kaviani, 2023; Hosseini & Alizadeh, 2023). Research shows that when teachers possess higher levels of digital and media literacy, they are more likely to engage in student-centered pedagogical practices and utilize digital content with greater pedagogical intentionality (Lähdesmäki & Maunula, 2023; Lee et al., 2023).

The supportive dimension of the model addresses the psychological, emotional, and technical needs of learners and educators. In the context of virtual education, where feelings of isolation, cognitive overload, and technical difficulties are common, structured support systems play a crucial role. Instructional support (e.g., workshops, feedback systems), motivational support (e.g., teacher-student rapport, recognition systems), and technical support (e.g., IT helpdesks, offline resources) collectively foster an inclusive and responsive learning environment (Devi et al., 2023; Shariati et al., 2024). Furthermore, these support systems contribute to educational equity by ensuring that students with diverse backgrounds and learning styles receive the resources they need to succeed (Tohidi, 2008; Unesco, 2020).

Media literacy also plays a central role in fostering critical citizenship and ethical digital behavior—objectives strongly emphasized in global education policy frameworks (Unesco, 2023a, 2023b). In the context of biology education, this extends to understanding misinformation related to science, evaluating online resources critically, and participating in informed digital discourse about health, environment, and biotechnology. As such, media literacy is not merely a technical skill but a civic competence that prepares learners to navigate complex sociotechnical systems responsibly (Hobbs, 2017; Potter, 2018).

The relevance of media literacy in science education has further been reinforced by neuroscience and motivation theories. According to self-determination theory, learners are more engaged when educational content aligns with their intrinsic motivations and provides autonomy, competence, and relatedness (Ryan & Deci, 2020). Media-rich virtual environments—if thoughtfully designed—can support these needs by enabling learner choice, fostering peer collaboration, and offering personalized feedback (Kargın & Demir, 2023; Lähdesmäki & Maunula, 2023).

Despite these pedagogical advantages, the implementation of media literacy in biology instruction faces practical challenges. These include teacher training deficits, lack of culturally relevant digital content, limited internet connectivity, and insufficient evaluation frameworks. Overcoming these barriers requires a systemic approach that includes curriculum redesign, teacher education reform, policy support, and stakeholder collaboration (Davarpanah et al., 2023; Mishra & Koehler, 2020; Unesco, 2023a).

In light of these considerations, the current study proposes a multilevel conceptual model that reflects the complexity of media literacy-based virtual education. The model is validated using structural equation modeling (SEM) and confirmatory factor analysis (CFA), ensuring empirical rigor and theoretical coherence. It is designed to guide curriculum developers, teacher educators, policymakers, and practitioners in creating effective, inclusive, and media-rich biology instruction for virtual platforms (Ebrahim Aziz Al-Zarji et al., 2024).

Ultimately, this research responds to a critical gap in the literature by offering a validated framework that operationalizes media literacy in the context of biology teaching in cyberspace.

2. Methods and Materials

In this study, in order to assess and validate the conceptual structure of the virtual media literacy education model in cyberspace, a quantitative research method and confirmatory factor analysis (CFA) within the framework of Structural Equation Modeling (SEM) were employed. The primary objective of this section was to examine the degree of fit between the empirical data and the dimensions and components identified during the qualitative phase of the research. The statistical population consisted of all high school biology teachers in Wasit Province, Iraq. From this population, a sample of 217 individuals was selected using simple random sampling.

The data collection instrument was a researcher-made questionnaire consisting of 66 items across three main dimensions (instructional, technological, and supportive), formatted on a five-point Likert scale. To ensure face and content validity, feedback was obtained from a panel of experts in the fields of virtual education and educational sciences, and necessary revisions were implemented accordingly.

Data analysis was conducted using SmartPLS version 3. Model validation was performed by examining factor loadings, Average Variance Extracted (AVE), Composite

Reliability (CR), and Cronbach's alpha. Factor loadings greater than 0.4, AVE values above 0.5, and CR values above 0.7 were considered acceptable thresholds. Furthermore, to assess discriminant validity, the Fornell–Larcker criterion was applied, and overall model fit indices such as RMSEA, GFI, CFI, χ^2/df, and SRMR were evaluated.

Findings from the confirmatory factor analysis indicated that the proposed model exhibited an acceptable fit, and the three dimensions—instructional, technological, and supportive—significantly explained the structure of the virtual media literacy education model. Among these, the instructional dimension had the highest factor loading, indicating the central role of educational content, teaching methods, and learner interactions in virtual biology instruction.

3. Findings and Results

The demographic characteristics of the respondents in this study indicate an acceptable degree of diversity in the composition of the sample, which is crucial for conducting advanced statistical analyses such as Confirmatory Factor Analysis (CFA). In terms of gender, 66% of participants were male and 34% were female. This distribution reflects a relative predominance of males in the statistical population; however, the meaningful participation of women also indicates gender diversity in the data.

Regarding age distribution, the highest frequency belonged to the 30–35 age group (32%), followed by the 35–40 age group (28%) and the 25–30 age group (27%). Those over 40 years old constituted only 13% of the population. This pattern suggests that most respondents were in the young to middle-aged category, reflecting both dynamism and moderate experience in teaching biology.

In terms of educational attainment, the majority of respondents held bachelor's degrees (52%) and master's degrees (40%), while only 5% had associate degrees and 3% held doctoral degrees. This distribution reflects a relatively high academic level within the studied population, enabling a more refined analysis of teachers' expert perspectives in the field of virtual education.

From the perspective of work experience, the largest share belonged to the 5–10 years range (37%), followed by those with less than 5 years (29%) and those with 10–15 years (26%). Only 8% of the respondents had more than 15 years of experience. These data suggest that the sample largely consisted of mid-career teachers who are likely well-acquainted with the current challenges and opportunities of virtual education in schools.

Table 1

Descriptive Results of Demographic Characteristics

Variable	Group	Frequency	Percentage
Gender	Male	143	0.66
	Female	74	0.34
	Total	217	1.00
Age	25–30	59	0.27
	30–35	69	0.32
	35–40	61	0.28
	>40	28	0.13
	Total	217	1.00
Education Level	Associate Degree	11	0.05
	Bachelor's Degree	113	0.52
	Master's Degree	87	0.40
	Doctorate	7	0.03
	Total	217	1.00
Work Experience	Less than 5 years	63	0.29
	5 to 10 years	80	0.37
	10 to 15 years	56	0.26
	More than 15 years	17	0.08
	Total	217	1.00

To examine the descriptive characteristics of the study's main variables and ensure the normal distribution of data, indicators such as mean, standard deviation, skewness, kurtosis, and the Kolmogorov–Smirnov test for normality were calculated for each component. Results showed that the mean values of the variables ranged from 2.61 to 3.54, indicating that respondents' evaluations of various aspects of virtual media literacy education were generally moderate to relatively favorable.

In the instructional dimension, the highest mean was associated with the component "interactive learning" (3.545), reflecting its perceived importance and prominence among the participating teachers. In contrast, "use of multimedia resources" had the lowest mean (2.61) among the instructional components. Other components—such as "media and information literacy education," "continuous assessment and feedback," and "teaching methods"—had mean values ranging from 3.10 to 3.23.

Within the supportive dimension, the component "instructional support" had a higher mean (3.144) compared to "psychological and motivational support" (2.846) and "technical support" (2.894). These results indicate that, from the respondents' viewpoint, instructional support holds a more prominent position than other forms of support.

In the technological dimension, the component "gamification and motivation in online education" had the highest mean (3.088), whereas "tools and technologies for teaching and learning" (2.659) and "design and structure of the online learning environment" (2.887) were rated lower.

Based on the values of skewness and kurtosis, all of which fell within the range of -1 to +1, the data distribution can be considered normal or near-normal. Additionally, the Kolmogorov–Smirnov test values for all components had significance levels above 0.05; thus, the null hypothesis of normal distribution was not rejected. This justifies the use of parametric analyses such as Confirmatory Factor Analysis.

Table 2

Descriptive Statistics for All Research Variables

Dimension	Component	Mean	SD	Skewness	Kurtosis	Z-statistic	p-value
Instructional	Media and Information Literacy Education	3.233	1.109	0.436	0.455	0.357	0.143
	Continuous Assessment and Feedback	3.106	1.106	0.244	0.438	0.342	0.158
	Use of Multimedia Resources	2.610	0.877	0.262	0.253	0.308	0.192
	Teaching Methods	2.870	1.074	0.230	0.339	0.346	0.154
	Interactive Learning	3.545	1.095	0.310	0.205	0.309	0.191
Supportive	Psychological and Motivational Support	2.846	1.024	0.276	0.289	0.308	0.192
	Instructional Support	3.144	0.847	0.227	0.373	0.371	0.129
	Technical Support	2.894	0.827	0.309	0.410	0.306	0.194
Technological	Tools and Technologies for Teaching/Learning	2.659	1.106	0.235	0.203	0.206	0.294
	Gamification and Motivation in Online Ed.	3.088	0.849	0.223	0.484	0.221	0.279
	Design and Structure of Online Learning Env.	2.887	1.144	0.435	0.490	0.354	0.146

In this study, to evaluate the structural validity of the virtual media literacy education model in cyberspace for teaching biology, a multilevel confirmatory factor analysis (CFA) was employed. Unlike exploratory factor analysis, which is conducted without a theoretical presumption, confirmatory factor analysis is based on a pre-specified theoretical model, and the researcher tests its accuracy against empirical data. The conceptual structure in this study consisted of one main variable, three dimensions (instructional, technological, supportive), eleven components, and 65 indicators examined across three levels of measurement.

The model was estimated in two stages: first in the standardized coefficients mode (Figure 1), and then in the significance coefficients mode (Figure 2). At the first level, relationships between indicators and components were analyzed; at the second level, relationships among components and dimensions; and at the third level, relationships between dimensions and the main variable of the model. According to the results, all standardized factor loadings across all three levels were above 0.4 and statistically significant, as their t-values fell outside the ±1.96 range, indicating significance at the 95% confidence level.

To assess the reliability of the measurement model, Cronbach's alpha, composite reliability (CR), and Rho_A indices were calculated. In all constructs, these values exceeded the threshold of 0.7 for alpha and CR, and 0.6 for Rho_A, indicating acceptable construct reliability. Convergent validity was also assessed using Average Variance Extracted (AVE) and its comparison with CR. In all constructs, AVE was above 0.5, and CR was greater than AVE, all of which conform to the criteria proposed by Joseph et al. (2016).

Discriminant validity was confirmed using two criteria: AVE > MSV and HTMT < 0.9. HTMT values for all interconstruct relationships were reported below 0.9, and AVE values for each construct were greater than their respective Maximum Shared Variance (MSV) with other constructs. These findings indicate a satisfactory level of distinction among the constructs in the model.

The results of the multilevel confirmatory factor analysis indicated that the proposed conceptual model demonstrates good statistical fit, acceptable reliability, and strong convergent and discriminant validity. These findings confirm that the designed model can be considered a reliable framework for developing virtual media literacy education in biology instruction.

Figure 1

Model with Standardized Coefficient Estimation

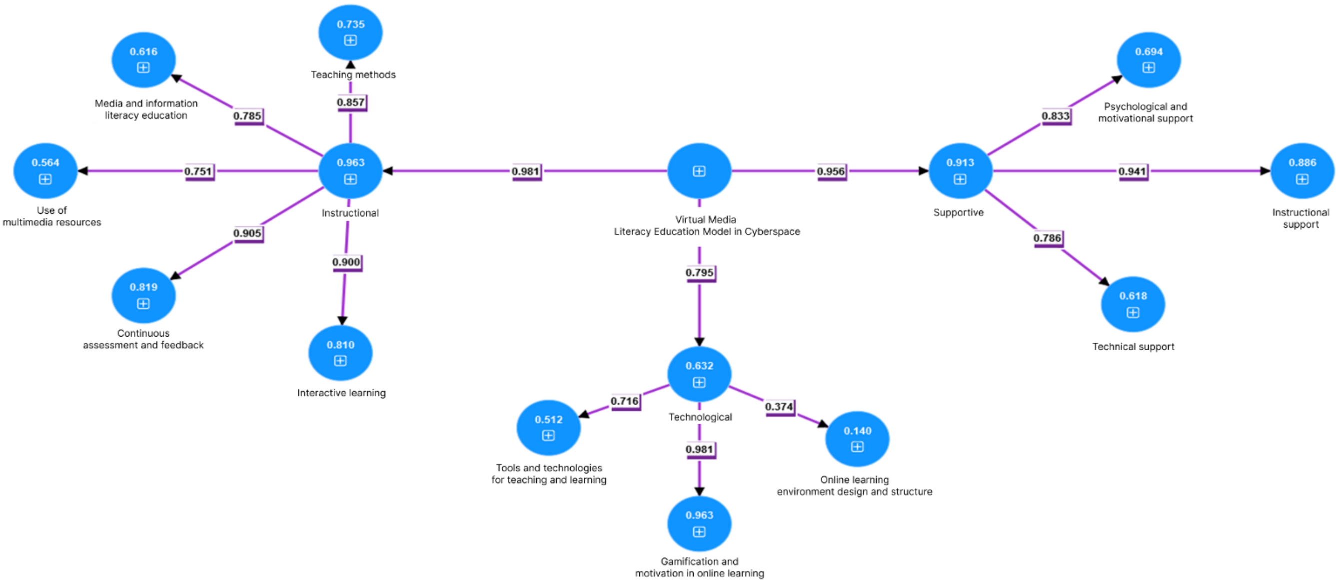
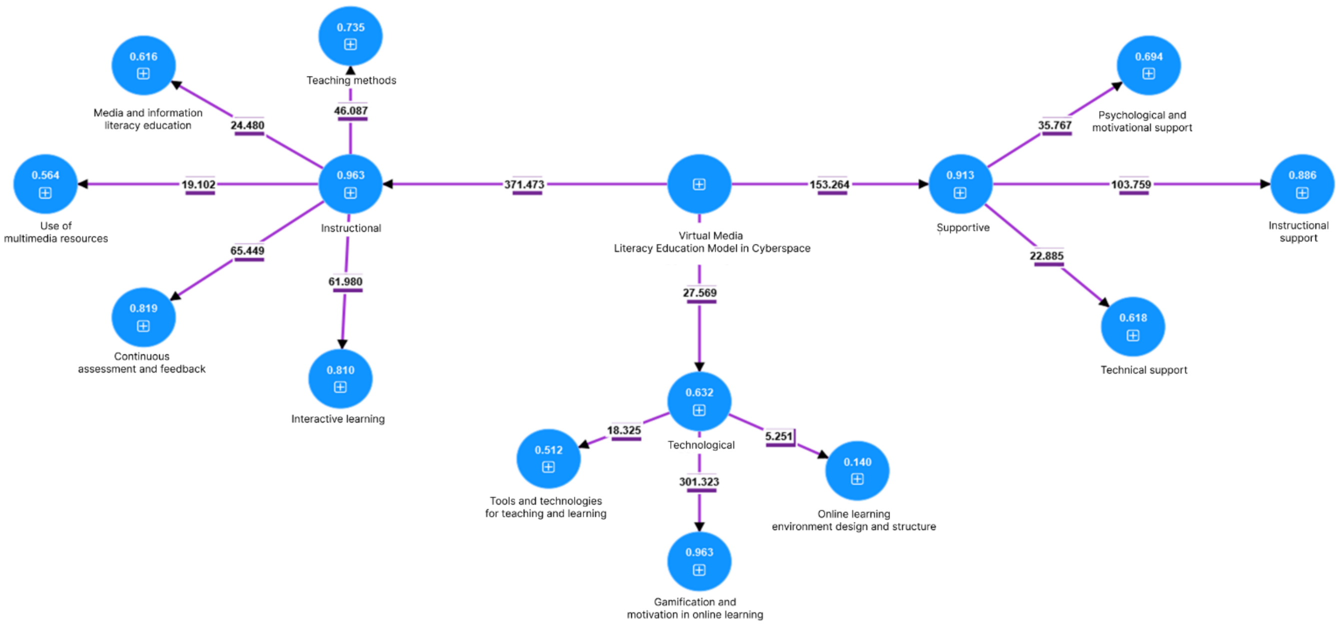


Figure 2

Model with Significance Coefficient Estimation



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To evaluate the quality of construct measurement within the conceptual model, convergent validity and construct reliability indices were used. In this regard, factor loadings, t-values, significance levels, and variance inflation factor (VIF) for all items were calculated. According to the results presented, all factor loadings exceeded 0.6, and corresponding t-values were all significant at the 0.001 level and above 1.96. Thus, all indicators were significantly associated with their respective components, indicating statistically strong convergent validity between the indicators and their underlying constructs.

From a reliability perspective, Cronbach's alpha and composite reliability (CR), calculated based on the same factor loadings and reported in subsequent tables, revealed that all constructs had reliability values exceeding 0.7. Therefore, the internal consistency of the questionnaire can be considered acceptable.

Additionally, VIF values for most indicators ranged from 1.3 to 4.0, and no indicator exceeded the VIF threshold of 5. Thus, there is no evidence of multicollinearity among indicators, and the indicators exhibit relative independence.

Notably, several indicators had very high factor loadings (above 0.9), reflecting their strong explanatory power for the latent constructs. Examples include "ability to create and produce content in the online environment" (factor loading = 0.923), "individualized feedback" (0.923), "responding to questions" (0.929), and "allocating time for practice" (0.919). These items represent key indicators in the virtual media literacy education model design.

Overall, the results derived from the factor loading analysis, t-values, and VIF indices indicate the establishment of appropriate convergent validity and acceptable reliability across all dimensions and components of the model, providing a solid basis for subsequent structural analyses.

Table 3

Results of Factor Loadings and Collinearity Index (VIF)

Dimension	Component	Indicator	Factor Loading	t-statistic	Significance Level	VIF
Instructional	Teaching Methods	Scientific storytelling	0.866	16.394	0.001	1.356
		Self-instruction and exploratory activities	0.857	16.439	0.001	2.700
		Group project design	0.716	16.136	0.001	1.889
		Active Q&A	0.856	15.152	0.001	1.933
		Mini-projects and practical tasks	0.784	15.242	0.001	4.056
		Problem-based teaching	0.843	12.485	0.001	3.789
		Project-based learning activities	0.659	17.318	0.001	1.644
Media and Information Literacy Education	Teaching search skills and identifying credible sources	0.786	18.167	0.001	2.078	
	Media ethics and online responsibility	0.863	16.152	0.001	1.933	
	Critical thinking and information analysis	0.699	18.727	0.001	2.067	
	Enhancing communication skills in cyberspace	0.800	17.530	0.001	3.378	
	Ability to create and produce content online	0.923	14.712	0.001	2.711	
	Cybersecurity awareness	0.723	14.348	0.001	4.033	
Use of Multimedia Resources	Educational videos and scientific documentaries	0.656	17.970	0.001	2.611	
	Classroom management software and platforms	0.817	16.864	0.001	1.944	
	3D model design tools	0.867	12.409	0.001	2.633	
	Scientific podcasts and audio files	0.795	13.788	0.001	3.133	
	Use of educational animations	0.912	14.076	0.001	3.656	
	Use of video conferencing software	0.677	16.455	0.001	1.856	
Continuous Assessment and Feedback	Use of data analysis tools	0.711	17.879	0.001	1.600	
	Providing practical suggestions	0.788	14.636	0.001	2.089	
	Individualized feedback	0.923	16.106	0.001	2.078	

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	Use of progress analysis tools	0.885	17.924	0.001	1.500	
	Use of data analysis tools	0.674	13.939	0.001	3.467	
	Quick assessment and feedback	0.729	18.682	0.001	2.611	
	Use of progress analysis tools	0.895	16.879	0.001	3.722	
	Use of periodic surveys	0.657	17.667	0.001	4.056	
	Use of interactive online quizzes	0.680	16.318	0.001	3.656	
	Development of online educational games	0.806	16.621	0.001	3.256	
Interactive Learning	Strengthening group interactions	0.802	14.818	0.001	2.978	
	Interactive learning using AR and VR	0.792	15.288	0.001	3.456	
	Group discussions and collaborative activities	0.844	16.333	0.001	2.644	
	Creation and use of interactive platforms	0.882	16.152	0.001	4.022	
	Use of interactive simulators	0.844	13.288	0.001	3.922	
	Interactive educational platforms	0.687	15.803	0.001	1.378	
	Video conferencing and live teaching tools	0.646	13.500	0.001	2.411	
	Use of digital libraries	0.685	18.015	0.001	3.333	
	Scientific images and infographics	0.840	16.894	0.001	1.567	
	Mobile applications	0.736	18.803	0.001	3.189	
Technological	Tools and Technologies for Teaching and Learning	AI-based educational platforms	0.643	13.000	0.001	2.067
Gamification and Motivation in Online Learning	Online educational competitions	0.724	18.985	0.001	1.689	
	Rewarding students	0.786	15.258	0.001	1.578	
	Development of educational games	0.722	16.364	0.001	2.433	
	Blended classes	0.877	12.818	0.001	1.400	
	Two-way communication	0.773	16.591	0.001	1.689	
	Use of visually appealing content	0.890	17.500	0.001	1.544	
	Simple and user-friendly interface design	0.707	15.273	0.001	1.844	
Design and Structure of the Online Learning Environment	Interactive environments and scientific simulations	0.724	14.833	0.001	3.356	
Supportive	Psychological and Motivational Support	Awareness sessions for parents	0.899	14.318	0.001	3.867
	Motivation enhancement	0.875	17.394	0.001	3.022	
	Teacher-student communication	0.754	14.939	0.001	2.011	
	Online counseling sessions	0.793	16.697	0.001	1.600	
Technical Support	Providing offline educational resources	0.833	13.939	0.001	3.733	
	Supplementary classes	0.889	13.758	0.001	1.767	
	Technical problem-solving workshops	0.808	18.106	0.001	1.467	
	Infrastructure development	0.658	12.242	0.001	2.356	
	Answering questions	0.929	13.061	0.001	3.422	
Instructional Support	Teacher training workshops	0.852	16.667	0.001	3.822	
	Support for various learning styles	0.924	16.318	0.001	3.456	
	Answering questions	0.747	14.197	0.001	1.344	
	Platform usage training sessions	0.853	12.727	0.001	4.033	
	Online supplementary sessions	0.864	17.485	0.001	3.778	
	Allocating time for practice	0.919	14.394	0.001	3.822	
	Use of lightweight platforms	0.801	12.212	0.001	2.256	
	Flexible learning in time and place	0.738	12.333	0.001	2.933	

To determine the degree of influence of each dimension, component, and indicator in the virtual media literacy education model in cyberspace, first-, second-, and third-order factor loading analyses were conducted. These

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analyses served as a basis for prioritizing the model variables according to their explanatory power.

At the macro-dimensional level, the results of third-order factor loading analysis revealed that the instructional dimension, with a factor loading of 0.981, had the greatest impact on explaining the main construct and was identified as the most influential dimension in virtual media literacy education. This was followed by the supportive dimension with a factor loading of 0.956 in second place, and the technological dimension with a factor loading of 0.795 in third place. These findings suggest that content, methods, and teaching–learning strategies are the most critical factors in the success of virtual education, and that technology, despite its importance, cannot be effective without instructional support and efficient methods.

At the component level, within the instructional dimension, the components “continuous assessment and feedback” (0.905) and “interactive learning” (0.900) had the highest factor loadings. These two components underscore the importance of two-way interaction, individualized feedback, and ongoing review processes in virtual education. The component “teaching methods” ranked third with a factor loading of 0.857.

In the supportive dimension, the component “instructional support” had the highest priority with a factor loading of 0.941. This finding highlights the significance of access to supplementary content, instructional sessions, and expert responses to student inquiries. “Psychological and motivational support” (0.833) and “technical support” (0.786) followed in order of importance.

In the technological dimension, the component “gamification and motivation in online learning” stood out with a remarkably high factor loading of 0.981. This indicates that integrating game-like, competitive, and engaging elements into virtual content can significantly boost learner motivation and participation. The component “teaching technology tools” (0.716) ranked second, while “online learning environment design” ranked third with a relatively low factor loading (0.374), pointing to the need for a serious re-evaluation of the structure and user experience of virtual learning environments.

At the indicator level, “responding to questions (technical support)” emerged as the strongest indicator with a factor loading of 0.929. This suggests that the quick, accurate, and accessible responses provided by teachers or technical support personnel play a vital role in the success of virtual education. Other high-priority indicators included “supporting various learning styles” and “individualized feedback” with factor loadings of 0.924 and 0.923, respectively, emphasizing the need for personalized instruction and direct interaction with learners. Additionally, “ability to create and produce content in the online space” (0.923) reflects the importance of digital content production skills in virtual learning environments.

Table 4

Results of Second- and Third-Order Factor Loadings

Dimension	Component	Factor Loading	t-statistic	Significance Level
Instructional	Media and information literacy education	0.785	24.480	0.001
	Continuous assessment and feedback	0.905	65.449	0.001
	Use of multimedia resources	0.751	19.102	0.001
	Teaching methods	0.857	46.087	0.001
	Interactive learning	0.900	61.980	0.001
Supportive	Psychological and motivational support	0.833	35.767	0.001
	Instructional support	0.941	103.759	0.001
	Technical support	0.786	22.885	0.001
Technological	Tools and technologies for teaching and learning	0.716	18.325	0.001
	Gamification and motivation in online learning	0.981	301.323	0.001
	Online learning environment design and structure	0.374	5.251	0.001
Main Construct	Instructional dimension	0.981	371.473	0.001
	Supportive dimension	0.956	153.264	0.001
	Technological dimension	0.795	27.569	0.001

In the evaluation of the outer measurement model, three key indices were examined: indicator reliability, construct reliability, and convergent validity. First, indicator reliability was assessed through the analysis of factor loadings and their significance. According to the results, all items had factor loadings greater than 0.7 and statistically significant t-values at the 95% confidence level ($t > 1.96$). This indicates the effective contribution of items in explaining the latent variables and satisfactory reliability at the indicator level. Additionally, the VIF values for all items were reported to be below 4, demonstrating that multicollinearity among indicators is not present and that the model is stable in this regard.

In the next step, construct reliability was evaluated using Cronbach's alpha and Composite Reliability (CR). As shown, Cronbach's alpha for all latent variables exceeded 0.8 and, in most cases, surpassed 0.9, indicating high internal consistency and coherence among items within each construct. Similarly, CR values for all constructs exceeded the 0.7 threshold, confirming strong reliability in the measurement model. Moreover, Rho_A values for all variables were also above the standard threshold of 0.7.

Convergent validity was assessed using the Average Variance Extracted (AVE) index. The AVE values for all constructs exceeded the minimum acceptable value of 0.5, indicating that a substantial proportion of variance in the indicators was explained by their corresponding latent variables. Therefore, convergent validity was confirmed for all constructs.

The results of the reliability and convergent validity analysis demonstrate that the measurement model possesses acceptable validation and high conceptual coherence, and that the data support the proposed model. This provides a valid foundation for structural model analysis and for examining causal relationships among variables in the next stages of the research.

Table 5

Convergent Validity Assessment of the Model

Latent Variables	Cronbach's Alpha (CA > 0.6)	Rho_A (> 0.7)	Composite Reliability CR (> 0.7)	AVE (> 0.5)
Media and Information Literacy Education	0.892	0.899	0.918	0.653
Continuous Assessment and Feedback	0.894	0.905	0.914	0.518
Use of Multimedia Resources	0.800	0.803	0.858	0.503
Gamification and Motivation in Online Learning	0.902	0.903	0.923	0.630
Teaching Methods	0.899	0.901	0.921	0.624
Psychological and Motivational Support	0.832	0.853	0.887	0.664
Instructional Support	0.905	0.914	0.925	0.609
Technical Support	0.783	0.785	0.860	0.607
Interactive Learning	0.882	0.901	0.906	0.501
Instructional Dimension	0.959	0.962	0.962	0.640
Technological Dimension	0.889	0.898	0.912	0.644
Supportive Dimension	0.925	0.930	0.935	0.678
Virtual Media Literacy Education in Cyberspace	0.974	0.977	0.976	0.692

In this study, discriminant validity of the measurement model constructs was assessed using the Fornell–Larcker criterion (1981). According to this method, discriminant validity is established when the square root of the AVE for each latent variable (presented on the diagonal of the matrix) is greater than its correlations with other constructs. In other words, a construct must explain more variance with its own indicators than with those of other constructs.

According to the results, the square roots of the AVE values for all latent variables are placed in the diagonal cells of the matrix (bolded values). These values show that in all cases, the square root of AVE is greater than the construct's correlation with other constructs. For example, the square root of AVE for "Media and Information Literacy Education" is 0.808, which exceeds its highest correlation with other variables (approximately 0.636 with "Use of Multimedia Resources"). This trend is also observed in other components such as "Continuous Assessment and Feedback" (0.72), "Instructional Support" (0.78), and "Gamification and Motivation in Online Learning" (0.794).

These results indicate that all constructs have acceptable discriminant validity and are statistically well distinguished from one another. Additionally, all correlation coefficients between variables were statistically significant at the 95% confidence level, suggesting theoretically coherent yet empirically distinct relationships among constructs. Based on the Fornell–Larcker criterion, it can be concluded that the present study's measurement model demonstrates strong discriminant validity, with well-defined and distinct conceptual constructs.

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Table 6

Fornell–Larcker Matrix

	1	2	3	4	5	6	7	8	9	10	11
1. Media & Info Literacy	0.808										
2. Teaching Tech Tools	0.373	1									
3. Assessment & Feedback	0.610	0.441	0.720								
4. Multimedia Resources	0.636	0.391	0.569	0.709							
5. Gamification & Motivation	0.550	0.593	0.659	0.482	0.794						
6. Teaching Methods	0.573	0.460	0.740	0.544	0.523	0.790					
7. Online Learning Design	0.295	0.354	0.319	0.273	0.243	0.308	1				
8. Psychological Support	0.610	0.351	0.639	0.479	0.593	0.623	0.161	0.815			
9. Instructional Support	0.618	0.418	0.825	0.591	0.657	0.778	0.240	0.669	0.780		
10. Technical Support	0.559	0.375	0.632	0.600	0.554	0.565	0.334	0.565	0.615	0.779	
11. Interactive Learning	0.600	0.445	0.685	0.612	0.605	0.710	0.348	0.718			

In structural equation modeling, evaluating model fit is of critical importance, as it indicates the extent to which the theoretical model aligns with empirical data. Good model fit suggests that the conceptual framework accurately explains the relationships between latent and observed variables. In this study, two widely accepted indices were used to assess model fit: the Standardized Root Mean Square Residual (SRMR) and the Goodness-of-Fit Index (GOF).

1. SRMR Index: SRMR measures the model's error in reproducing the observed correlation matrix. It reflects the discrepancy between the actual data correlation matrix and the one reproduced by the model. According to accepted criteria, an SRMR value less than 0.12 is considered acceptable (Henseler et al., 2015). In the model under study, the SRMR value was 0.081, indicating a good fit between the model and the data, with low approximation error in predicting the correlation structure.

2. GOF Index: The GOF index, as a composite criterion of measurement and structural model fit, provides an overall evaluation of model quality. It is calculated based on the geometric mean of commonality and the mean R^2 of endogenous variables:

$$\text{GOF} = \sqrt{(\text{average commonality} \times \text{average } R^2)} = \sqrt{(0.740 \times 0.839)} = 0.621$$

According to Wetzels et al. (2009), a GOF value greater than 0.36 indicates strong model fit. In the present study, the calculated GOF of 0.621 exceeds the recommended threshold, indicating excellent overall model fit and the model's strong ability to explain the variance in the dependent variables.

The combination of SRMR and GOF results confirms that the conceptual model developed in this study demonstrates good fit, strong theoretical consistency, and high explanatory power. Therefore, the structural validity of the model can be confidently used to interpret findings and develop practical recommendations.

Table 7

Model Fit Indices

Model Fit Index	Symbol	Estimated Value	Acceptable Threshold
Standardized Root Mean Square Residual	SRMR	0.081	< 0.12
Goodness-of-Fit	GOF	0.621	> 0.36

4. Discussion and Conclusion

The results of this study confirm the conceptual and statistical validity of a media literacy-based virtual education model for teaching biology in cyberspace. Using multilevel confirmatory factor analysis (CFA), the model demonstrated strong factorial loadings at three levels—indicators, components, and dimensions. Among the three main dimensions of the model, the instructional dimension showed the highest explanatory power with a factor loading of 0.981, followed by the supportive dimension (0.956), and the technological dimension (0.795). These findings indicate that instructional strategies, content delivery, and learning processes are the most critical factors in ensuring the success of virtual biology education, even more so than the technology itself. This aligns with findings that emphasize

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pedagogy as the cornerstone of effective digital learning environments (Means et al., 2014; Mishra & Koehler, 2020).

Within the instructional dimension, the components "continuous assessment and feedback" and "interactive learning" had the strongest loadings (0.905 and 0.900, respectively). This confirms the essential role of two-way communication, adaptive feedback, and sustained learner engagement in digital biology instruction. These findings are supported by studies that have highlighted the significance of interaction and feedback mechanisms in maintaining student motivation and promoting deeper understanding in online settings (Dewi, 2023; Ryan & Deci, 2020). In particular, digital environments that support formative feedback, peer collaboration, and authentic tasks have been shown to enhance learning outcomes in science education (Abdi, 2019; Davarpanah et al., 2023).

The technological dimension, while rated third, remains integral to the success of the model. The component "gamification and motivation in online learning" had a remarkably high factor loading (0.981), indicating the importance of engaging instructional design. This resonates with recent research emphasizing the motivational power of game-based elements such as challenges, rewards, and interactive scenarios in virtual science instruction (Binh, 2020; Kargın & Demir, 2023). Conversely, the relatively lower loading of the "design of the virtual learning environment" component (0.374) suggests that many existing platforms lack the usability, interactivity, or personalization features that promote effective learning. This reflects concerns in the literature about the suboptimal design of virtual education environments, which often fail to meet learner expectations (Ghahremani & Kaviani, 2023; Korona, 2024).

In the supportive dimension, "instructional support" was the most significant component (0.941), highlighting the need for continuous professional development, access to educational resources, and teacher responsiveness. These findings echo the call for structural support systems that reduce teacher workload, foster pedagogical innovation, and provide technical assistance in virtual settings (Hosseini & Alizadeh, 2023; Shariati et al., 2024). Furthermore, "psychological and motivational support" (0.833) and "technical support" (0.786) were also notable, underscoring the emotional and cognitive challenges that students face in online learning environments. The need for comprehensive support is well documented, especially in contexts where students must navigate uncertainty, isolation, and technological barriers (Devi et al., 2023; Lee et al., 2023).

At the indicator level, the item "responding to questions (technical support)" had the highest factor loading (0.929), followed by "support for various learning styles" and "individualized feedback" (0.924 and 0.923, respectively). These results emphasize the importance of personalized, responsive, and flexible learning environments that recognize learner diversity and provide real-time support. This finding is consistent with the principles of universal design for learning (UDL) and culturally responsive pedagogy, which advocate for inclusive and adaptive approaches in digital education (Lähdesmäki & Maunula, 2023; Unesco, 2023a).

The evaluation of model validity through reliability and convergence indices also confirmed the robustness of the proposed framework. All constructs demonstrated Cronbach's alpha values above 0.8 and AVE values above 0.5, indicating high internal consistency and convergent validity. Discriminant validity was confirmed using the Fornell–Larcker criterion, which showed that each construct was empirically distinct from others. Moreover, model fit indices such as SRMR (0.081) and GOF (0.621) demonstrated that the proposed model was statistically sound and capable of explaining a substantial proportion of variance in virtual biology education outcomes. These indicators align with similar model validation studies in the educational field (Ebrahim Aziz Al-Zarji et al., 2024; Navarro et al., 2024).

The empirical strength of the model supports the theoretical frameworks underpinning it. For instance, the TPACK model argues that successful technology integration in education requires a fusion of technological, pedagogical, and content knowledge (Mishra & Koehler, 2020). The high loadings of instructional and technological components in this study validate this conceptual triad. Additionally, the findings resonate with the SAMR model, which advocates for transformative uses of technology in education that redefine learning tasks (Puentedura, 2020). Gamification and content co-creation are clear examples of redefinition-level activities that were found to be highly influential in the model.

Media literacy plays a central role in the success of this model, not merely as a technical skill but as a pedagogical and civic competency. The ability of students to critically evaluate digital content, collaborate online, and produce scientific media is essential in contemporary science education (Hobbs, 2017; Potter, 2018). This is especially relevant in the biology classroom, where learners are frequently exposed to scientific misinformation and must develop the ability to verify sources, interpret data, and engage in ethical digital behaviors (Devi et al., 2023; UNESCO, 2023b). The model's strong emphasis on media literacy also supports broader educational goals such as critical thinking, problem-solving, and democratic participation (Ryan & Deci, 2020; Unesco, 2020).

These findings also have implications for teacher professional development. As previous studies have shown, many teachers lack confidence in integrating digital media into instruction due to limited training and conceptual understanding of media literacy (Korona, 2024; Shariati et al., 2024). The model presented in this study provides a framework that teacher training programs can adopt to promote digital pedagogical competencies. Furthermore, it reinforces the importance of aligning educational policy with the evolving demands of virtual instruction and scientific literacy in the 21st century (Lee et al., 2023; Unesco, 2023a).

In sum, the present research confirms that a well-structured, media literacy-based model can enhance the quality, equity, and engagement of virtual biology instruction. The model's three-dimensional architecture—combining pedagogical depth, technological utility, and systemic support—provides a comprehensive blueprint for designing effective online science education. These findings reinforce the urgency of transitioning from technology-focused interventions to integrated, learner-centered models that place media literacy at the core of curriculum design.

Despite the robustness of the findings, this study is not without limitations. First, the data were collected from a sample limited to high school biology teachers in a specific geographical region, which may limit the generalizability of the results to other subject areas or educational contexts. Second, the study employed self-report questionnaires, which are inherently subject to social desirability bias and subjective interpretation. Third, although the model was statistically validated, the study did not examine actual learning outcomes or student perspectives, which are critical for evaluating instructional effectiveness in practice. Fourth, the cross-sectional nature of the research limits the ability to assess the long-term applicability or sustainability of the model.

Future research should consider applying this model to other subject areas such as chemistry, physics, or environmental sciences to evaluate its broader applicability. Longitudinal studies can also explore how sustained use of this model affects student engagement, academic achievement, and digital citizenship skills over time. Furthermore, experimental designs involving control and intervention groups would offer stronger causal evidence for the model's effectiveness. Finally, incorporating students' voices through qualitative methods such as interviews and focus groups could enrich the understanding of how learners experience media literacy-based virtual instruction.

Educational institutions should adopt this model as a framework for designing and implementing virtual science curricula. Teachers should be trained not only in technological tools but also in media literacy pedagogy, including content creation, ethical engagement, and critical thinking. Policymakers should ensure that infrastructures—both digital and organizational—support sustained instructional and technical assistance. Curriculum developers should integrate interactive and gamified elements into biology content to increase engagement. Finally, ongoing assessment and feedback systems should be institutionalized to support data-driven improvements in virtual instruction.

Authors' Contributions

Authors equally contributed to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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Ethical Considerations

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All procedures performed in studies involving human participants were under the ethical standards of the institutional and, or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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