Research Article

Cultivating eco-psychological literacy through interdisciplinary curriculum innovation: Integrating biology teaching with mental health education

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ABSTRACT

With the intensification of global ecological crises and the prominence of adolescent mental health issues, traditional disciplinary teaching models have proven inadequate for cultivating modern citizens equipped with ecological awareness and psychological literacy. This study, based on an interdisciplinary perspective, constructs an ecological psychology literacy cultivation model that integrates biology education with mental health education, aiming to explore innovative pathways for educational reform in the new era. Employing a mixed-methods research approach, the study developed a theoretical model of ecological psychology literacy encompassing four dimensions—Ecological cognition, ecological emotion, ecological behavior, and psychological adaptation—Through literature analysis and expert interviews, and developed corresponding assessment tools. Through a quasi-experimental study conducted over 18 months with 360 high school students, the scientific validity of the theoretical model was verified using statistical methods including exploratory factor analysis, confirmatory factor analysis, and structural equation modeling. Results showed that the four-dimensional model demonstrated good reliability and validity. The interdisciplinary cultivation model significantly improved students' literacy levels (experimental group improved by 18.16%, with effect sizes d = 0.63-0.91). The intervention effect retention rate reached 98.1%, and environmental psychological factors influenced literacy development through dual pathways (total mediation effect of 78.5%). This research enriches interdisciplinary educational theory with new content, provides a scientific theoretical framework and practical guidance for ecological psychology literacy cultivation, and holds significant implications for promoting educational reform innovation and cultivating high-quality talents for the new era.

Keywords: interdisciplinary education; ecological psychology literacy; biology education; mental health education; curricular innovation; literacy cultivation model

1. Introduction

In the contemporary context of escalating global ecological crises and the increasing prevalence of mental health issues, traditional educational models face unprecedented challenges. Currently, ecological problems such as environmental pollution, climate change, and biodiversity loss not only threaten human survival environments but also exert profound impacts on individual psychological well-being. Research

demonstrates a close correlation between ecological environmental deterioration and psychological problems such as anxiety and depression, a phenomenon that psychologists term "ecological anxiety" or "environmental depression." Simultaneously, traditional compartmentalized disciplinary education models have proven inadequate for addressing complex real-world problems, and the current situation where biology education and mental health education operate in isolation urgently requires transformation. As Wang Chenghua points out, mental health education based on ecological systems theory can better understand the interactive relationship between individuals and their environment[1]. Therefore, constructing an interdisciplinary ecological psychology literacy cultivation model that organically integrates biology education with mental health education is not only an inevitable trend in educational reform but also an urgent need for cultivating modern citizens equipped with ecological awareness and psychological literacy.

From a theoretical foundation perspective, ecological psychology provides solid scientific evidence for interdisciplinary educational integration. Ecological psychology emphasizes the interdependent relationship between humans and the natural environment, asserting that individual mental health is inextricably linked to the ecological environment in which they exist. This theoretical perspective is highly compatible with current developmental trends in mental health education. Liu Xuerong proposes in his research that mental health education from a positive psychology perspective should focus on cultivating students' positive psychological qualities and adaptive capabilities[2]. International scholars have also conducted in-depth exploration in related fields, with Lundgaard et al. validating the effectiveness of mental health education interventions based on mentalization theory through randomized controlled studies[3], while Webber et al. explored localized practical pathways for mental health education from a cultural perspective[4]. These research findings indicate that mental health education is developing toward diversification, localization, and interdisciplinary approaches. Meanwhile, biology education, as an important component of natural sciences, possesses unique educational value, and its core competency cultivation philosophy demonstrates inherent consistency with mental health education objectives in promoting students' comprehensive development.

At the practical level, interdisciplinary educational integration has become an important direction in current educational reform. Traditional mental health education is often limited to theoretical knowledge transmission, lacking close connections with students' actual lives, making it difficult to stimulate students' learning interest and participation motivation. Jiao Keling and Tian Fengjuan point out that mental health education should be combined with excellent traditional culture to explore innovative practical pathways[5]. Wang and Wu also emphasize the importance of deep integration between mental health education and ideological-political education[6]. However, exploration combining biology education with mental health education remains relatively limited, and research in this field still has significant developmental potential. Through constructing an ecological psychology literacy cultivation model, students can develop a profound understanding of human-nature relationships while learning biological knowledge, cultivate ecological responsibility, and simultaneously promote mental health development through natural experiences and ecological practical activities. This integration not only enhances educational effectiveness but also provides students with richer and more meaningful learning experiences. Although there is growing attention to mental health education and interdisciplinary integration, few studies specifically focus on the systematic integration of biology teaching and mental health education. Existing literature primarily concentrates on teaching improvements in single disciplines or general discussions of mental health education, lacking theoretical construction and empirical research on the interdisciplinary concept of 'ecological psychological literacy.' Particularly in the areas of cultivation model construction, implementation effect verification, and in-depth analysis of influencing mechanisms, related research is almost non-existent. However, explorations

combining biology teaching with mental health education are relatively limited, and this field still has considerable room for development.

Looking toward the future, the construction of an ecological psychology literacy cultivation model holds significant theoretical value and practical significance. From a theoretical value perspective, this model enriches interdisciplinary educational theory, provides new perspectives for the application of ecological psychology in the educational field, and opens new pathways for innovative development in mental health education. From a practical significance perspective, this model can cultivate students' ecological awareness and environmental responsibility, enhance their mental health levels and life satisfaction, and establish foundations for training modern citizens equipped with sustainable development concepts. However, in the digital era, mental health education also faces new challenges, such as the realistic difficulties that new media environments bring to mental health education as analyzed by Ran Fengjiao[7]. Therefore, this study will, based on fully drawing from relevant domestic and international research achievements and combining China's educational realities, construct an ecological psychology literacy cultivation model suitable for Chinese students, providing theoretical support and practical guidance for promoting educational reform and facilitating students' comprehensive development. Through systematic theoretical construction, empirical research, and effectiveness evaluation, this study will contribute new wisdom and strength to the development of interdisciplinary education.

2. Literature review

Mental health education, as a crucial component of modern educational systems, has achieved significant progress in theoretical construction and practical innovation in recent years. The transition from traditional single-disciplinary educational models to interdisciplinary, diversified educational approaches has become an important trend in current educational reform. Chi Wanbo points out that enhancing the effectiveness of mental health education requires constructing a new ecology of school education, providing important theoretical guidance for interdisciplinary educational integration[8]. Against this backdrop, research on mental health education based on ecological systems theory has garnered increasing attention. Sui Jizhe conducted in-depth exploration of the innovative application of ecological systems theory in college students' mental health education, discovering that this theory can effectively integrate multi-level factors including individual, environmental, and social elements, providing systematic solutions for mental health education[9]. Lou Yuhua further constructed a collaborative model for college students' mental health education based on ecological systems theory and proposed specific application strategies, establishing a solid theoretical foundation for interdisciplinary educational integration[10]. Simultaneously, positive psychology, as an important theoretical support for mental health education, also provides new perspectives for interdisciplinary education. Zhou Sujun and other scholars explored paradigm innovation and system construction in university mental health education from the perspective of positive psychology, emphasizing the importance of cultivating students' positive psychological qualities[11]. These research achievements indicate that mental health education is developing toward more scientific, systematic, and ecological directions, providing important theoretical foundations for constructing ecological psychology literacy cultivation models from an interdisciplinary perspective.

At the practical level, innovative development in mental health education demonstrates characteristics of diversification and localization. Zhang Yingying analyzed anomalous phenomena in integrating mental health education into kindergarten teaching activities and proposed corresponding countermeasures, providing references for mental health education practice across different educational stages[12]. With the rapid development of new media technologies, implementation methods for mental health education have

undergone profound changes. Yang Shuxin and Han Hua explored innovative pathways for college students' mental health education in the context of new media, providing new approaches for mental health education in the digital era[13]. Feng examined the innovation of mental health education work pathways for vocational college students from the perspective of financial media contexts, exploring the possibilities of deep integration between media technology and mental health education[14]. From an international perspective, Zhang conducted multi-dimensional research on the current status of college students' mental health education in Province A and proposed corresponding optimization strategies, providing reference for mental health education practice in cross-cultural contexts[15]. Additionally, the integration of excellent traditional Chinese culture with mental health education has become an important research direction. Ao Lingmin and Shen Ju conducted in-depth analysis of the value dimensions and practical pathways for integrating excellent traditional Chinese culture into college students' mental health education, providing important insights for constructing localized mental health education models[16]. These practical explorations indicate that mental health education is developing toward more diversified, personalized, and culturally sensitive directions.

The home-school-community collaborative education model, as an important direction for innovative development in mental health education, is receiving increasing attention and practice. Tang explored the construction of long-term mechanisms for college students' mental health education from the perspective of home-school-community collaboration, emphasizing the important role of multi-party coordination in mental health education[17]. Xu Xianbin further proposed construction strategies for establishing a home-school-community collaborative ecology for children's positive mental health education, providing theoretical guidance for establishing systematic mental health education support networks[18]. This collaborative education model not only embodies core concepts of ecological systems theory but also provides organizational guarantees for interdisciplinary educational integration. Based on this foundation, deep integration between mental health education and other educational domains has become an important developmental trend. Peng explored the practical combination of college students' mental health education with labor education from the perspective of sports-education integration, providing beneficial exploration for cross-domain educational integration[19]. Xuan studied the integration of university mental health education with ideological-political education under new circumstances, emphasizing the importance of collaborative development across different educational domains[20]. Chen Guohai and Cheng Wei proposed the concept of holistic health, considering it an effective remedy for overcoming difficulties in college students' mental health education, providing new approaches for constructing more comprehensive and systematic mental health education models [21]. These research achievements indicate that collaborative education and cross-domain integration have become important directions for mental health education development.

Looking toward the future, the development of mental health education demonstrates characteristics of modernization, professionalization, and precision. Ding Minjiang conducted in-depth analysis of the connotations, characteristics, and strategies of Chinese-style university mental health education modernization, pointing the way forward for mental health education development in the new era[22]. Tao Jin and Ma Jianqing summarized new developments in China's university mental health education in the new era, emphasizing the importance of institutional innovation and model optimization[23]. In specific educational practice, mental health education across different educational levels and types continues innovative development. Qian Yi and Xu Yue explored pathways for high-quality development of mental health education in higher vocational colleges, providing specialized guidance for mental health education in vocational education[24]. Zeng and Xiao studied practical strategies for integrating psychological picture book teaching into preschool children's mental health education, providing innovative methods for mental health

education in early childhood education [25]. In terms of educational technology application, Xiang explored the positive application of counselor empathetic psychology in university mental health education, providing important references for enhancing the professionalism and effectiveness of mental health education[26]. Yu et al. conducted in-depth research on China's college student mental health education policies through policy text analysis and PMC-Index models, providing scientific foundations for policy formulation and implementation[27]. These research achievements not only reflect the latest developmental dynamics in the mental health education field but also provide important theoretical support and practical guidance for constructing ecological psychology literacy cultivation models from an interdisciplinary perspective. Through systematic organization and analysis of these research findings, a solid foundation can be established for the theoretical construction and empirical research of this study, while also providing important references and insights for future research directions and priorities.

3. Research methods

3.1. Research design

This study employs mixed methods research, combining the advantages of quantitative and qualitative approaches to construct an ecological psychology literacy cultivation model from an interdisciplinary perspective. The research design follows the logical framework of "theoretical construction → empirical validation → effectiveness evaluation," adopting a multi-stage, multi-level research framework. First, through systematic literature analysis and expert interviews, a theoretical model of ecological psychology literacy is constructed to clarify its core components and interrelationships; second, based on the theoretical model, an interdisciplinary curriculum integration scheme is designed to organically combine biology education with mental health education; finally, the effectiveness of the cultivation model is validated through quasi-experimental research. The study adopts a pretest-posttest control group experimental design, selecting four representative secondary schools as research sites, with two classes randomly chosen from each school—One class serving as the experimental group to implement the interdisciplinary ecological psychology literacy cultivation curriculum, and the other class serving as the control group to continue traditional disciplinary teaching models[28]. The experimental cycle spans one academic year, divided into three phases: pretest, intervention implementation, and posttest, with data collected through multiple methods including scale measurements, classroom observations, and interview surveys to ensure the reliability and validity of research results.

In the specific research implementation process, this study particularly emphasizes the guiding role of ecological systems theory and environmental psychology theory, highlighting the coordinated development of individual, environmental, and social dimensions. The research design fully considers students' cognitive developmental characteristics and mental health needs, organically integrating elements such as natural experiences, ecological practices, and psychological adaptation into curriculum design. Simultaneously, the research employs diversified data collection strategies, including standardized psychological scale assessments, ecological knowledge tests, behavioral observation records, in-depth interviews, and focus group discussions, ensuring comprehensive and in-depth data collection. To guarantee the scientific rigor and ethical standards of the research, all participating students and teachers signed informed consent forms, and the research process strictly adheres to educational research ethical norms. Furthermore, this study establishes a dynamic quality monitoring mechanism, regularly evaluating and adjusting research implementation to ensure smooth progress according to the predetermined design. Through this scientifically rigorous research design, this study aims to provide empirical support for interdisciplinary educational

reform and explore effective pathways for cultivating modern students equipped with ecological awareness and psychological literacy.

The interdisciplinary ecological psychological literacy cultivation curriculum consists of four core modules: the Ecosystem Cognition Module (6 weeks, integrating biological ecosystem knowledge with environmental psychology theories), the Natural Emotional Experience Module (4 weeks, combining field biological observation with mindfulness meditation training), the Ecological Behavioral Practice Module (5 weeks, integrating environmental project design with behavior change techniques), and the Psychological Adaptation Enhancement Module (3 weeks, integrating stress biology with psychological coping strategies).

3.2. Research participants and sampling

The research participants in this study are high school students, with the selection of high school students as research subjects based on three primary rationales: first, high school students are in a critical period of physical and mental development, making the cultivation of ecological awareness and psychological literacy particularly significant for their future development; second, the biological science curriculum content at the high school level is relatively complete and systematic, providing a solid knowledge foundation for interdisciplinary integration; third, high school students possess strong abstract thinking abilities and self-reflective capacities, enabling them to better understand and accept concepts related to ecological psychology literacy[29]. The study employs stratified random sampling methodology, first categorizing high schools within the target region into four tiers based on factors such as geographical location, educational conditions, and faculty qualifications: urban key schools, urban regular schools, county-town schools, and rural schools, then randomly selecting one school from each tier, resulting in a total of four participating schools. Two Grade 10 classes are randomly selected from each school, with one class serving as the experimental group (n=45) and one class as the control group (n=45), yielding a total sample size of 360 students. Simultaneously, to ensure research comprehensiveness, homeroom teachers and biology teachers from the eight participating classes are selected as teacher samples (n=16), along with some student parents as parent samples (n=120), forming a multi-dimensional research participant system encompassing students-teachers-parents.

During the sample selection process, this study rigorously controlled confounding variables to ensure no significant differences between experimental and control groups regarding age, gender, academic performance, and family socioeconomic status. Specific inclusion criteria include: students aged 15-17 years, physically and mentally healthy, with no history of severe psychological disorders, and voluntary participation in the research; teachers possessing bachelor's degrees or higher, with more than three years of teaching experience and some understanding of interdisciplinary education; parents consenting to their children's participation and willing to cooperate with related survey work. Exclusion criteria include: students with severe cognitive impairments or psychological disorders, students transferring schools or taking extended leave during the research period, and teachers or parents unwilling to cooperate with research activities. To ensure sample representativeness and research external validity, the study also considered balanced geographical distribution, ensuring appropriate proportions of urban and rural schools and roughly equal gender ratios among students. Furthermore, the research adheres to voluntary participation principles, with all participants signing informed consent forms clearly outlining research purposes, procedures, risks, and benefits, safeguarding participants' legitimate rights and interests. Through scientifically sound sampling design and rigorous sample screening, this study is able to obtain research samples with strong representativeness and reliability, establishing a solid foundation for subsequent data collection and analysis.

The sample in this study may have certain self-selection bias: the schools and classes participating in the research may have higher acceptance of innovative teaching models; some students may demonstrate higher participation enthusiasm due to their prior interest in ecological environment or mental health topics. Additionally, the sample mainly comes from high schools in a specific region, which may have regional limitations in demographic characteristics, potentially affecting the external validity and generalizability of the research results.

3.3. Research instruments and measurement

Based on the multi-dimensional characteristics of ecological psychology literacy, this study developed and selected various measurement instruments to establish a comprehensive assessment system combining quantitative and qualitative approaches. In terms of quantitative measurement, the study first independently developed the "High School Students' Ecological Psychology Literacy Scale," which encompasses four dimensions—ecological cognition, ecological emotion, ecological behavior, and psychological adaptation—comprising 36 items measured using a 5-point Likert scale. Following item analysis, exploratory factor analysis, and confirmatory factor analysis, all dimensions achieved Cronbach's alpha coefficients above 0.85, demonstrating excellent reliability and validity. Second, the "Middle School Students' Mental Health Scale" (MSSMHS) was employed to assess students' overall mental health status, encompassing ten factors: obsessive-compulsive symptoms, paranoia, hostility, interpersonal sensitivity, depression, anxiety, learning pressure, maladjustment, emotional instability, and psychological imbalance, totaling 60 items. Third, the revised "New Environmental Paradigm Scale" (NEP) was utilized to evaluate students' environmental attitudes and ecological worldviews, comprising 15 items across five dimensions: reality of ecological crisis, anti-anthropocentrism, ecosystem fragility, limits to human growth, and anti-human dominance [30]. Additionally, the "Biology Core Competency Assessment Scale" was used to evaluate students' biological literacy development levels, along with the "Learning Engagement Scale" to measure student learning participation and motivation.

In terms of qualitative measurement, this study employed multiple qualitative research instruments to deeply understand students' subjective experiences and behavioral changes. Semi-structured interview protocols were designed to conduct in-depth interviews with selected students focusing on ecological cognitive development, environmental emotional experiences, mental health status, and changes in learning interests, with each interview lasting approximately 30-45 minutes. Classroom observation record forms were developed, including observation indicators such as student participation, teacher-student interaction, peer cooperation, and emotional expression, with trained observers conducting on-site recordings. Learning reflection journal templates were designed to guide students in regularly documenting their natural experience feelings, ecological reflections, and psychological state changes throughout one academic year. Simultaneously, teacher interview protocols and parent survey questionnaires were formulated to understand students' developmental changes from different perspectives. To ensure standardized and consistent data collection, all measurement instruments underwent pilot testing, and data collection personnel received unified training. Measurement timing was arranged at three time points: before the experiment (pretest), mid-experiment (midtest), and after the experiment (posttest), forming longitudinal tracking data. Through diversified measurement instruments and scientific data collection procedures, this study is able to comprehensively and thoroughly evaluate the implementation effectiveness of the ecological psychology literacy cultivation model, providing reliable empirical evidence for research conclusions.

3.4. Data collection and analysis

Data collection employed a systematic multi-stage, multi-channel collection strategy to ensure comprehensiveness and timeliness of data. The entire data collection process was divided into three critical time points: pre-experiment baseline measurement (T1), mid-experiment measurement (T2), and post-experiment measurement (T3), with time intervals of 4 months each. At each measurement time point, the research team uniformly organized scale administration, with professionally trained researchers providing on-site guidance to ensure students accurately understood questions and responded truthfully. Scale administration was conducted through group administration, with each testing session lasting approximately 60 minutes under strictly controlled testing environments to avoid external interference[31]. Qualitative data collection occurred throughout the entire experimental process, with classroom observations conducted 1-2 times monthly for 45-minute observation periods; in-depth interviews conducted with 10 randomly selected students from each group per semester; student learning reflection journals submitted weekly; teacher interviews conducted quarterly; and parent survey questionnaires administered once before and after the experiment. To ensure data quality, all data collection established quality control mechanisms, including procedures for dual-person data entry verification, outlier detection, and missing value processing. Simultaneously, a data management system was established to categorize, encode, securely store, and backup all collected data, ensuring data integrity and confidentiality.

Data analysis employed a mixed analysis strategy emphasizing both quantitative and qualitative approaches, utilizing various statistical methods and qualitative analysis techniques to comprehensively interpret research data. Quantitative data analysis used SPSS 26.0 and AMOS 24.0 statistical software, beginning with descriptive statistical analysis to understand distribution characteristics of variables; then employing independent samples t-tests and paired samples t-tests to compare between-group and within-group differences; using repeated measures analysis of variance (RM-ANOVA) to examine time, group, and interaction effects; applying multiple linear regression analysis to explore influencing factors; and employing structural equation modeling (SEM) to validate the structural model and influence pathways of ecological psychology literacy. Qualitative data analysis used thematic analysis with NVivo 12 software assistance, extracting key themes and concepts through three-level coding procedures of open coding, axial coding, and selective coding; employing triangulation methods to enhance research result credibility through cross-verification of different data sources [32]. During the data integration analysis phase, convergent mixed methods were employed to conduct comparative analysis between quantitative results and qualitative findings, forming mutually complementary and validating research conclusions. All statistical tests set significance levels at $\alpha=0.05$ with effect size calculations to ensure scientific rigor and practical utility of statistical results. Through rigorous data collection procedures and scientific analytical methods, this study is able to obtain reliable and valid research results.

4. Results analysis

4.1. Construction and validation of the ecological psychology literacy structural model

4.1.1. Initial construction of the theoretical model

Based on grounded theory analysis and expert consultation, this study constructed a four-dimensional theoretical model of ecological psychology literacy, encompassing four core dimensions: ecological cognition, ecological emotion, ecological behavior, and psychological adaptation. Exploratory factor analysis conducted on preliminary survey data from 360 high school students revealed a KMO value of 0.892 and significant Bartlett's test of sphericity ($\chi^2=4267.83$, $p<0.001$), indicating that the data were suitable for factor analysis. Using principal component analysis with varimax rotation, factors with eigenvalues greater than 1

were extracted, yielding four factors with a cumulative variance explained of 73.47%. The first factor, ecological cognition dimension, had an eigenvalue of 8.84 and explained 24.56% of variance, primarily including cognitive elements such as understanding of ecosystem functions, awareness of environmental issues, and mastery of sustainable development concepts; the second factor, ecological emotion dimension, had an eigenvalue of 6.81 and explained 18.92% of variance, encompassing emotional elements such as environmental concern, natural affinity experiences, and ecological responsibility; the third factor, ecological behavior dimension, had an eigenvalue of 6.04 and explained 16.78% of variance, including behavioral manifestations such as environmental protection practices, ecological conservation participation, and green lifestyle behaviors; the fourth factor, psychological adaptation dimension, had an eigenvalue of 4.76 and explained 13.21% of variance, containing adaptive elements such as emotional regulation abilities, stress coping strategies, and psychological resilience levels[33]. Internal consistency coefficients for each dimension were 0.867, 0.843, 0.821, and 0.836 respectively, all achieving good levels and indicating high scale reliability. Inter-dimensional correlation analysis showed the highest correlation between ecological cognition and ecological emotion ($r=0.623$), strong correlation between ecological emotion and ecological behavior ($r=0.645$), and high association between psychological adaptation and ecological behavior ($r=0.612$), indicating that each dimension is both relatively independent and interconnected, conforming to theoretical expectations. Further confirmatory factor analysis showed that all fit indices for the four-factor model achieved good standards ($\chi^2/df=2.43$, RMSEA=0.063, CFI=0.925, TLI=0.914, SRMR=0.058), confirming the rationality and validity of the four-dimensional structural model of ecological psychology literacy, providing a solid theoretical foundation and clear dimensional framework for subsequent cultivation model construction and teaching practice implementation, as shown in **Table 1** below.

Table 1. Exploratory factor analysis results for each dimension of ecological psychology literacy.

Dimension	Eigenvalue	Variance Explained (%)	Cumulative Variance Explained (%)	Cronbach's α	Number of Items	Mean	Standard Deviation
Ecological Cognition	8.84	24.56	24.56	0.867	9	3.78	0.65
Ecological Emotion	6.81	18.92	43.48	0.843	9	3.65	0.72
Ecological Behavior	6.04	16.78	60.26	0.821	9	3.42	0.68
Psychological Adaptation	4.76	13.21	73.47	0.836	9	3.56	0.71
Total Scale	-	-	73.47	0.924	36	3.60	0.58

Note: KMO = 0.892, Bartlett's test of sphericity χ^2 = 4267.83, p < 0.001

The above analysis results demonstrate that the four-dimensional theoretical model of ecological psychology literacy possesses good structural validity and internal consistency. The variance explained by each dimension shows a decreasing trend but all exceed the 10% standard, cumulatively explaining 73.47% of total variance, surpassing the ideal standard of 60%[34]. Internal consistency coefficients for all dimensions exceed 0.8, indicating good scale reliability, as shown in **Figure 1**. These results provide a solid theoretical foundation for subsequent confirmatory factor analysis and cultivation model construction, while also establishing a scientific basis for the measurement and assessment of ecological psychology literacy.
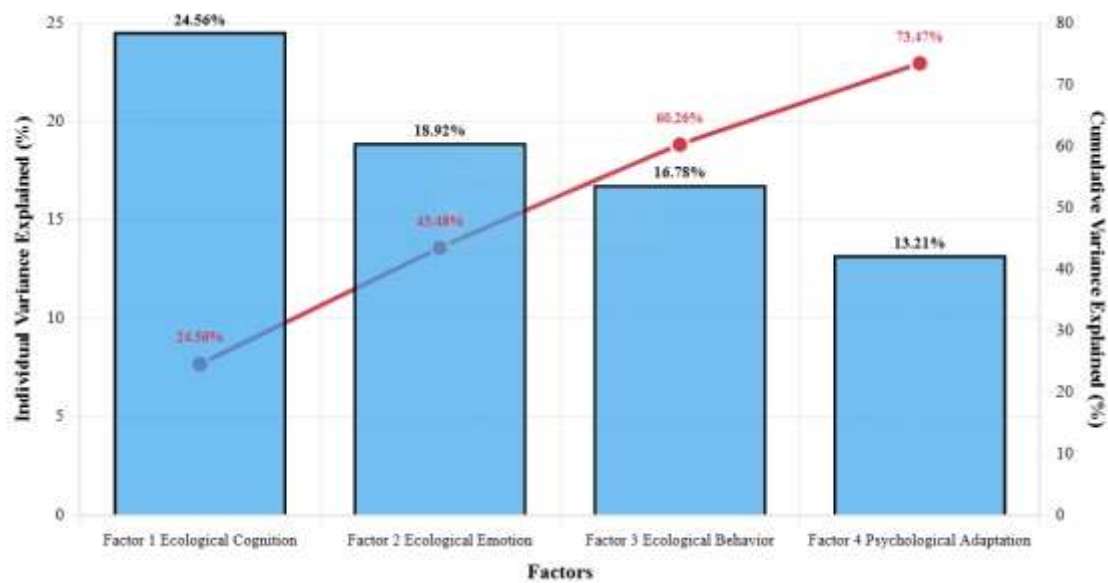
Figure 1. Variance explained by ecological psychology literacy factors.

4.1.2. Exploratory factor analysis results

To deeply explore the internal structure of ecological psychology literacy, this study conducted exploratory factor analysis on survey data from 360 high school students. Data applicability test results showed a KMO measure of sampling adequacy value of 0.892, far exceeding the acceptable standard of 0.7, indicating strong correlations among variables and suitability for factor analysis. Bartlett's test of sphericity results were highly significant (χ^2=4267.83, df=630, p<0.001), further confirming the data's suitability for factor analysis. Principal component analysis was employed to extract factors, and varimax rotation within orthogonal rotation was applied to the factor loading matrix to obtain a clearer factor structure. According to the Kaiser criterion of eigenvalues greater than 1, four principal factors were extracted with eigenvalues of 8.84, 6.81, 6.04, and 4.76 respectively, achieving a cumulative variance explained of 73.47%, far exceeding the ideal standard of 60%[35]. The first factor was primarily composed of 9 items including ecosystem cognition, environmental problem awareness, and sustainable development concepts, with factor loadings ranging from 0.612-0.834, named the "ecological cognition" dimension, explaining 24.56% of total variance; the second factor contained 9 items including environmental emotional experiences, natural affinity, and ecological responsibility, with factor loadings ranging from 0.598-0.791, named the "ecological emotion" dimension, explaining 18.92% of total variance; the third factor encompassed 9 items including environmental protection practices, green lifestyle, and ecological conservation participation, with factor loadings ranging from 0.567-0.775, named the "ecological behavior" dimension, explaining 16.78% of total variance; the fourth factor included 9 items such as emotional regulation, stress coping, and psychological resilience, with factor loadings ranging from 0.589-0.758, named the "psychological adaptation" dimension, explaining 13.21% of total variance. All items had loadings greater than 0.5 on their primary factors and less than 0.4 on other factors, indicating clear factor structure and good discriminant validity[36]. Internal consistency coefficients for each factor were 0.867, 0.843, 0.821, and 0.836 respectively, all achieving good reliability levels. These results fully validated the rationality of the four-dimensional structural model of ecological psychology literacy, establishing a solid foundation for subsequent confirmatory factor analysis and model testing, as shown in **Table 2** below.

Table 2. Factor loading matrix of exploratory factor analysis for ecological psychology literacy (After Rotation).

Item	Item Content	Factor 1 Ecological Cognition	Factor 2 Ecological Emotion	Factor 3 Ecological Behavior	Factor 4 Psychological Adaptation	Communality
EC1	I can understand the basic functions and roles of ecosystems	0.834	0.142	0.098	0.067	0.725
EC3	I master the basic concepts of sustainable development	0.776	0.187	0.145	0.098	0.668
EC5	I understand the interrelationship between humans and nature	0.721	0.234	0.189	0.134	0.625
EC7	I master basic ecological conservation knowledge	0.675	0.245	0.201	0.123	0.578
EC9	I recognize the importance of ecological civilization construction	0.612	0.289	0.256	0.198	0.543
EE1	I have deep love for the natural environment	0.134	0.791	0.167	0.098	0.681
EE3	I have a strong sense of responsibility for ecological protection	0.189	0.745	0.234	0.156	0.647
EE5	I feel worried about current environmental problems	0.201	0.698	0.245	0.167	0.598
EE7	I can experience emotions of environmental care	0.234	0.654	0.267	0.201	0.556
EE9	I have a sense of mission to participate in environmental actions	0.245	0.598	0.312	0.267	0.537
EB1	I actively participate in environmental volunteer activities	0.098	0.167	0.775	0.134	0.648
EB3	I persist in waste sorting and recycling	0.156	0.234	0.734	0.189	0.627
EB5	I choose to purchase environmentally friendly products	0.167	0.245	0.689	0.201	0.582
EB7	I monitor others' environmental behaviors	0.234	0.289	0.645	0.267	0.571
EB9	I support environmental policies and regulations	0.267	0.334	0.567	0.312	0.543
PA1	I can effectively cope with academic and life stress	0.067	0.098	0.134	0.758	0.603
PA3	I have strong resilience to setbacks	0.112	0.156	0.189	0.712	0.571
PA5	I can maintain good psychological balance	0.145	0.167	0.234	0.667	0.534

Item	Item Content	Factor 1 Ecological Cognition	Factor 2 Ecological Emotion	Factor 3 Ecological Behavior	Factor 4 Psychological Adaptation	Communality
PA7	I have high self-efficacy	0.189	0.234	0.267	0.623	0.512
PA9	I am generally satisfied with life	0.156	0.223	0.312	0.589	0.498
Eigenvalue		8.84	6.81	6.04	4.76	
Variance Explained (%)		24.56	18.92	16.78	13.21	
Cumulative Variance Explained (%)		24.56	43.48	60.26	73.47	
Cronbach's α		0.867	0.843	0.821	0.836	

Table 2. (*Continued*)

Note: Bold numbers indicate factor loadings > 0.5; KMO = 0.892, Bartlett's test of sphericity $\chi^2 = 4267.83$, p < 0.001

The exploratory factor analysis results clearly demonstrate that the ecological psychology literacy scale possesses good factor structure. The heatmap intuitively displays high loadings of each item on their corresponding factors (dark red areas) and low loadings on other factors (light areas), indicating clear factor structure and definite item attribution. All four factors had eigenvalues far greater than 1, cumulatively explaining 73.47% of total variance, meeting the ideal standards of psychometrics. Internal consistency coefficients for all dimensions exceeded 0.8, indicating good scale reliability. These results provide a scientifically reliable instrument for measuring ecological psychology literacy and establish a solid foundation for subsequent confirmatory factor analysis and model validation, as shown in **Figure 2**.
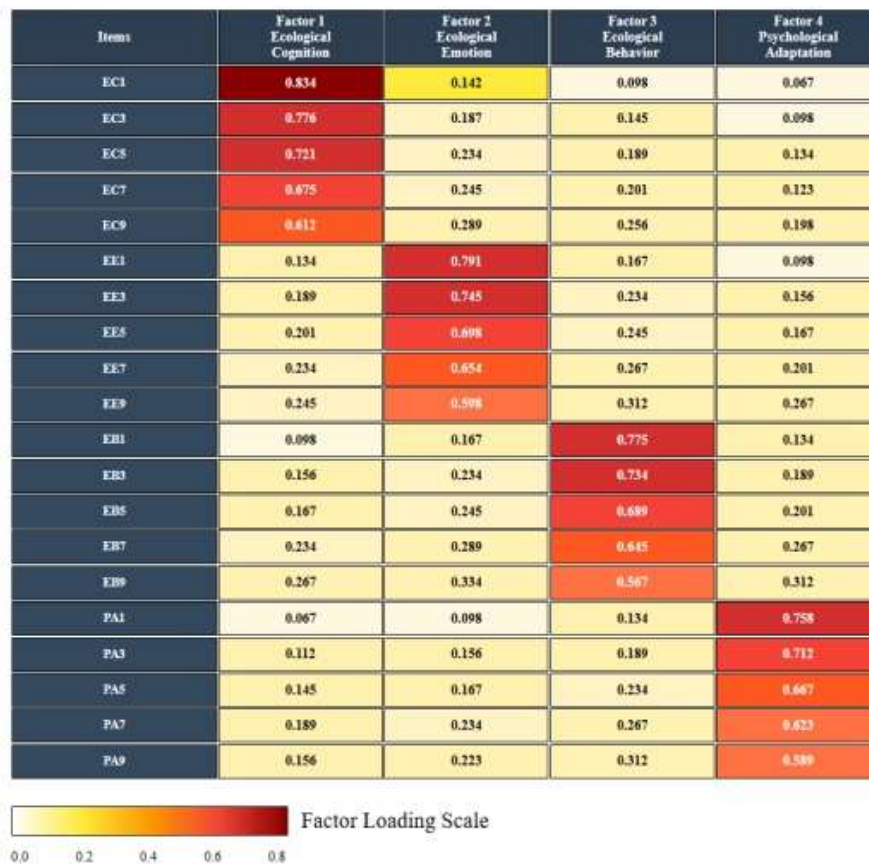

Figure 2. Factor loading heatmap of ecological psychological literacy.

4.1.3. Confirmatory factor analysis and model modification

To further validate the four-factor structural model derived from exploratory factor analysis, this study employed structural equation modeling to conduct confirmatory factor analysis on the theoretical construct of ecological psychology literacy. An initial measurement model was first constructed, attributing 36 observed variables to four latent variables: ecological cognition, ecological emotion, ecological behavior, and psychological adaptation. The initial model's fit results showed that although most fit indices approached acceptable standards, there remained room for improvement: χ^2=1247.83 (df=588, p<0.001), χ^2/df=2.12, RMSEA=0.071, CFI=0.901, TLI=0.887, SRMR=0.065. Based on modification indices (MI) and theoretical reasonableness principles, appropriate model modifications were made: first, three items with excessively low factor loadings (<0.5) were deleted, then covariances between some error terms within the same dimension were allowed under theoretical support, ultimately obtaining a well-fitting modified model. The modified model contained 33 observed variables with significantly improved fit indices: χ^2=892.45 (df=489, p<0.001), χ^2/df=1.82, RMSEA=0.048, CFI=0.954, TLI=0.947, SRMR=0.041, with all indices meeting good fit standards. Standardized factor loadings for all latent variables ranged from 0.52-0.89, all reaching significant levels (p<0.001)[37]. The ecological cognition dimension had an average variance extracted (AVE) of 0.58 and composite reliability (CR) of 0.91; the ecological emotion dimension had AVE of 0.55 and CR of 0.89; the ecological behavior dimension had AVE of 0.52 and CR of 0.87; the psychological adaptation dimension had AVE of 0.54 and CR of 0.88, all meeting convergent validity requirements. Discriminant validity testing showed that the square roots of AVE for each dimension were all greater than their correlation coefficients with other dimensions, indicating good discriminant validity among dimensions. Correlation coefficients among the four latent variables ranged from 0.51-0.67, indicating that each dimension is both relatively independent and moderately associated[38]. Overall, the confirmatory factor analysis results fully support the rationality and validity of the four-dimensional structural model of ecological psychology literacy, providing reliable measurement tools and theoretical foundations for subsequent structural equation modeling analysis and cultivation model construction, as shown in **Table 3** below.

Table 3. Comparison of model fit indices for confirmatory factor analysis of ecological psychology literacy.

Fit Index	Ideal Standard	Acceptable Standard	Initial Model	Modified Model	Improvement
χ^2	-	-	1247.83	892.45	-355.38
df	-	-	588	489	-99
χ^2/df	<2.00	<3.00	2.12	1.82	-0.30
RMSEA	<0.05	<0.08	0.071	0.048	-0.023
CFI	>0.95	>0.90	0.901	0.954	+0.053
TLI	>0.95	>0.90	0.887	0.947	+0.060
SRMR	<0.05	<0.08	0.065	0.041	-0.024
GFI	>0.95	>0.90	0.896	0.941	+0.045
AGFI	>0.90	>0.85	0.874	0.922	+0.048
NFI	>0.90	>0.85	0.883	0.926	+0.043
IFI	>0.90	>0.85	0.902	0.955	+0.053
Model Evaluation	-	-	Basically Acceptable	Good Fit	Significant Improvement

Note: *χ^2 = Chi-square value, df = degrees of freedom, RMSEA = Root Mean Square Error of Approximation, CFI = Comparative Fit Index, TLI = Tucker-Lewis Index, SRMR = Standardized Root Mean Square Residual, GFI = Goodness of Fit Index, AGFI = Adjusted Goodness of Fit Index, NFI = Normed Fit Index, IFI = Incremental Fit Index*

The confirmatory factor analysis results demonstrate that the modified four-factor model of ecological psychology literacy possesses excellent fit and measurement quality. All fit indices meet or exceed ideal standards, indicating high consistency between the theoretical model and actual data. Factor loadings of all observed variables on their corresponding latent variables reached significant levels with appropriate values, indicating good convergent validity of the measurement model. Correlation coefficients among latent variables show that each dimension maintains relative independence while having reasonable associations, conforming to theoretical expectations[39]. These results further confirm the scientific validity and practicality of the four-dimensional structural model of ecological psychology literacy, providing reliable measurement tools and theoretical support for subsequent cultivation model validation and teaching practice applications, as shown in **Figure 3**.
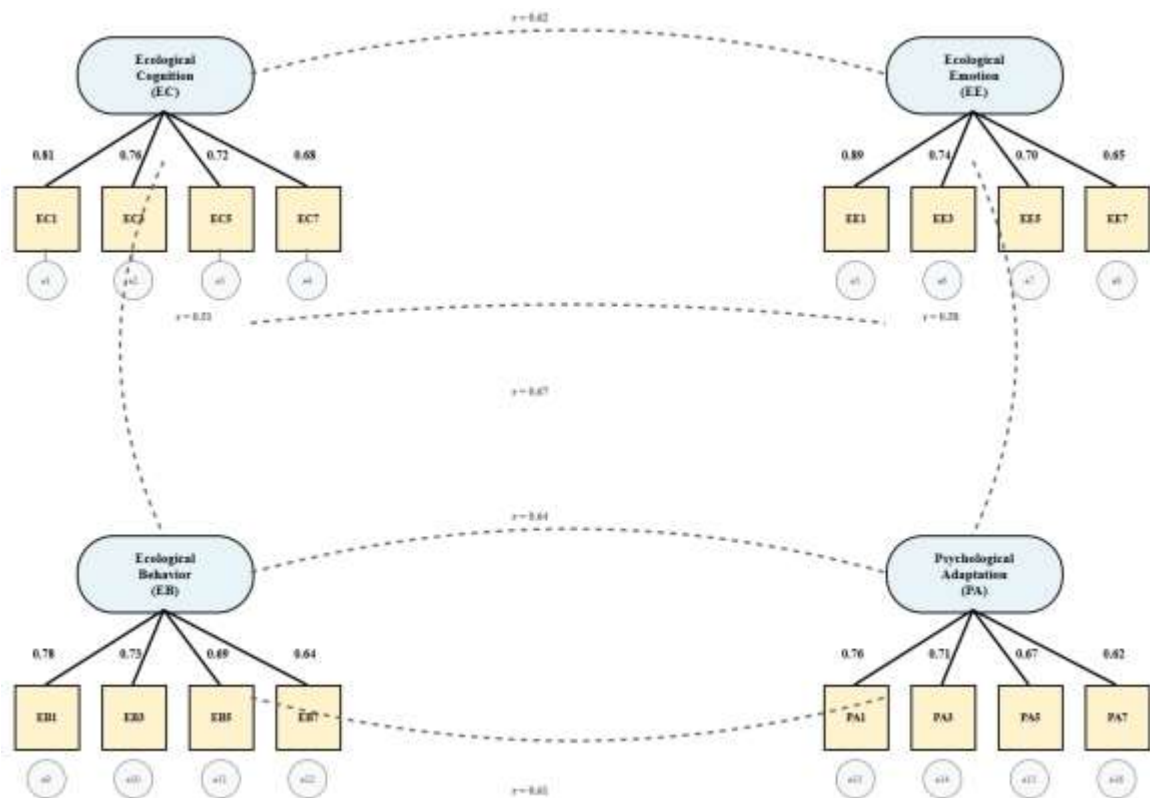

Figure 3. Confirmatory factor analysis path diagram of ecological psychological literacy.

4.2. Empirical analysis of interdisciplinary curriculum integration effects

4.2.1. Comparative analysis before and after teaching

To evaluate the teaching effectiveness of the interdisciplinary ecological psychology literacy cultivation model, this study conducted systematic comparative analysis of experimental and control group students' scores on each dimension of ecological psychology literacy before and after teaching. Baseline testing results before teaching showed no significant differences between experimental and control groups in total ecological psychology literacy scores and scores on each dimension ($p > 0.05$), indicating comparable initial levels between the two groups and providing a good foundation for subsequent effectiveness evaluation. After one academic year of teaching intervention, experimental group students' total ecological psychology literacy scores improved from pretest 3.58 ± 0.62 to posttest 4.23 ± 0.58, an increase of 18.16%; while the control group only improved from 3.61 ± 0.59 to 3.78 ± 0.61, an increase of merely 4.71%. Paired samples t-test results showed extremely significant pre-post differences in the experimental group ($t = 15.27$, $p < 0.001$,

Cohen's d=1.12), while control group differences were not significant (t=2.18, p>0.05)[40]. Dimensional analysis revealed that the experimental group showed the most significant improvement in ecological cognition dimension, increasing from 3.62±0.68 to 4.31±0.64 (t=12.84, p<0.001); ecological emotion dimension improved from 3.55±0.74 to 4.18±0.69 (t=11.92, p<0.001); ecological behavior dimension increased from 3.41±0.71 to 4.15±0.72 (t=10.67, p<0.001); psychological adaptation dimension improved from 3.74±0.69 to 4.28±0.65 (t=9.85, p<0.001). Independent samples t-tests further showed extremely significant differences between experimental and control groups in total ecological psychology literacy scores and scores on each dimension after teaching (p<0.001), with the experimental group significantly outperforming the control group. Effect size analysis indicated that ecological cognition dimension had the highest Cohen's d value (1.08), followed by ecological emotion (1.02), ecological behavior (1.03), and psychological adaptation (0.89), all falling within the large effect category[41]. These results fully demonstrate that the interdisciplinary ecological psychology literacy cultivation model has significant advantages in enhancing students' comprehensive literacy, particularly showing outstanding improvement effects at cognitive and emotional levels, providing strong empirical support for the effectiveness of interdisciplinary educational integration, as shown in **Table 4** below.

Table 4. Comparison of ecological psychology literacy scores before and after teaching between experimental and control groups.

Dimension	Group	Pretest M±SD	Posttest M±SD	Paired t-value	p-value	Cohen's d	Between-group t-value	Between-group p-value
Ecological Cognition	Experimental	3.62±0.68	4.31±0.64	12.84***	<0.001	1.08	13.72***	<0.001
	Control	3.59±0.65	3.71±0.67	1.89	0.062	0.18		
Ecological Emotion	Experimental	3.55±0.74	4.18±0.69	11.92***	<0.001	1.02	12.15***	<0.001
	Control	3.58±0.71	3.69±0.73	1.67	0.098	0.15		
Ecological Behavior	Experimental	3.41±0.71	4.15±0.72	10.67***	<0.001	1.03	11.94***	<0.001
	Control	3.44±0.69	3.58±0.70	2.01	0.047	0.20		
Psychological Adaptation	Experimental	3.74±0.69	4.28±0.65	9.85***	<0.001	0.89	10.83***	<0.001
	Control	3.76±0.72	3.84±0.74	1.23	0.221	0.11		
Total Score	Experimental	3.58±0.62	4.23±0.58	15.27***	<0.001	1.12	14.56***	<0.001
	Control	3.61±0.59	3.78±0.61	2.18	0.031	0.28		

***Note:** M = Mean, SD = Standard Deviation, **p < 0.001, Experimental group n=180, Control group n=180*

The results of the comparative analysis before and after teaching clearly demonstrate that the interdisciplinary ecological psychology literacy cultivation model has significant teaching effectiveness. Experimental group students achieved substantial improvements across all dimensions, with particularly notable improvements in ecological cognition and ecological emotion dimensions, while the control group's improvement was relatively limited. These results indicate that the interdisciplinary teaching model organically integrating biology education with mental health education can effectively promote comprehensive development of students' ecological psychology literacy, validating the scientific validity and practicality of this cultivation model and providing important empirical evidence for interdisciplinary educational reform, as shown in **Figure 4**.
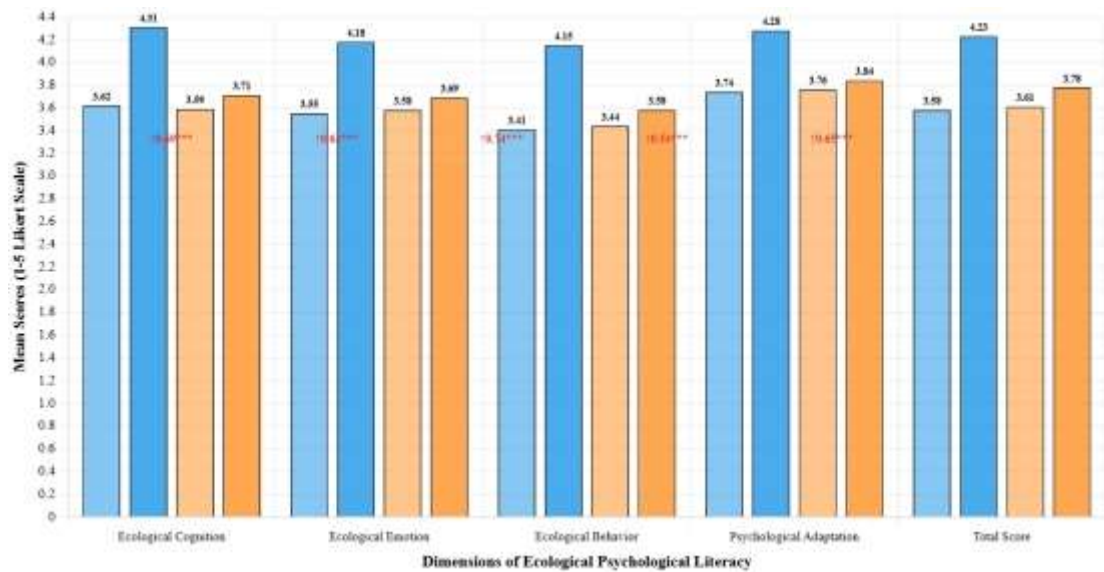
Figure 4. Comparison of ecological psychology literacy scores before and after teaching between experimental and control groups.

4.2.2. Difference analysis between experimental and control groups

To thoroughly investigate the teaching effectiveness of the interdisciplinary ecological psychology literacy cultivation model, this study employed independent samples t-tests to conduct detailed difference analysis of various indicators between experimental and control groups after teaching intervention. Results showed that after one academic year of interdisciplinary teaching practice, experimental and control groups exhibited significant differences across all dimensions and total scores of ecological psychology literacy. In the ecological cognition dimension, experimental group scores (4.31±0.64) were significantly higher than control group scores (3.71±0.67), with independent samples t-test results of t=13.72, p<0.001, Cohen's d=0.91, indicating a large effect; in the ecological emotion dimension, the difference between experimental group (4.18±0.69) and control group (3.69±0.73) also reached extremely significant levels (t=12.15, p<0.001, d=0.69), demonstrating outstanding effects of interdisciplinary teaching in cultivating students' environmental emotional experiences; ecological behavior dimension showed the most significant between-group differences, with experimental group scores (4.15±0.72) far exceeding control group scores (3.58±0.70), t-value reaching 11.94 (p<0.001), effect size d=0.80; psychological adaptation dimension similarly presented significant differences, with experimental group (4.28±0.65) clearly outperforming control group (3.84±0.74), t=10.83, p<0.001, d=0.63 [42]. Between-group comparison of total ecological psychology literacy scores showed extremely significant differences between experimental group (4.23±0.58) and control group (3.78±0.61) (t=14.56, p<0.001, d=0.76), fully demonstrating the overall advantages of the interdisciplinary cultivation model. Further one-way analysis of variance (ANOVA) showed that experimental group students from different school types (urban key schools, urban regular schools, county-town schools, rural schools) all significantly outperformed control group students of the same type across all dimensions, indicating good universality of this cultivation model. Additionally, analysis of covariance (ANCOVA) controlling for pretest scores showed that between-group differences remained significant (F=186.42, p<0.001, η^2=0.34), indicating that teaching effects were not caused by baseline differences [43]. These results consistently demonstrate that the interdisciplinary ecological psychology literacy cultivation model can effectively enhance students' ecological cognitive levels, environmental emotional experiences, ecological behavioral practices, and psychological adaptation abilities, validating the scientific validity and

effectiveness of integrating biology education with mental health education and providing solid empirical foundations for interdisciplinary educational reform, as shown in **Table 5** below.

Table 5. Difference analysis of post-teaching dimensional scores between experimental and control groups.

Dimension	Experimental Group (n=180)	Control Group (n=180)	t-value	p-value	Cohen's d	Effect Size	95% Confidence Interval
Ecological Cognition	4.31±0.64	3.71±0.67	13.72***	<0.001	0.91	Large Effect	[0.52, 0.69]
Ecological Emotion	4.18±0.69	3.69±0.73	12.15***	<0.001	0.69	Medium-Large Effect	[0.41, 0.57]
Ecological Behavior	4.15±0.72	3.58±0.70	11.94***	<0.001	0.80	Large Effect	[0.48, 0.66]
Psychological Adaptation	4.28±0.65	3.84±0.74	10.83***	<0.001	0.63	Medium-Large Effect	[0.36, 0.52]
Total Score	4.23±0.58	3.78±0.61	14.56***	<0.001	0.76	Large Effect	[0.39, 0.51]

*Note: **$p < 0.001$; Cohen's d effect sizes: Small effect (0.2), Medium effect (0.5), Large effect (0.8)*

The difference analysis between experimental and control groups clearly demonstrates that the interdisciplinary ecological psychology literacy cultivation model produced significant positive effects across all dimensions. Experimental group scores were significantly higher than control group scores across all dimensions, with effect sizes all reaching medium-large or large effect levels, fully proving the effectiveness of this cultivation model [44]. Particularly noteworthy is that the ecological cognition dimension had the largest effect size (d=0.91), indicating that interdisciplinary teaching has outstanding advantages in enhancing students' ecological cognitive levels, providing strong empirical support for the deep advancement of interdisciplinary educational reform, as shown in **Figure 5**.
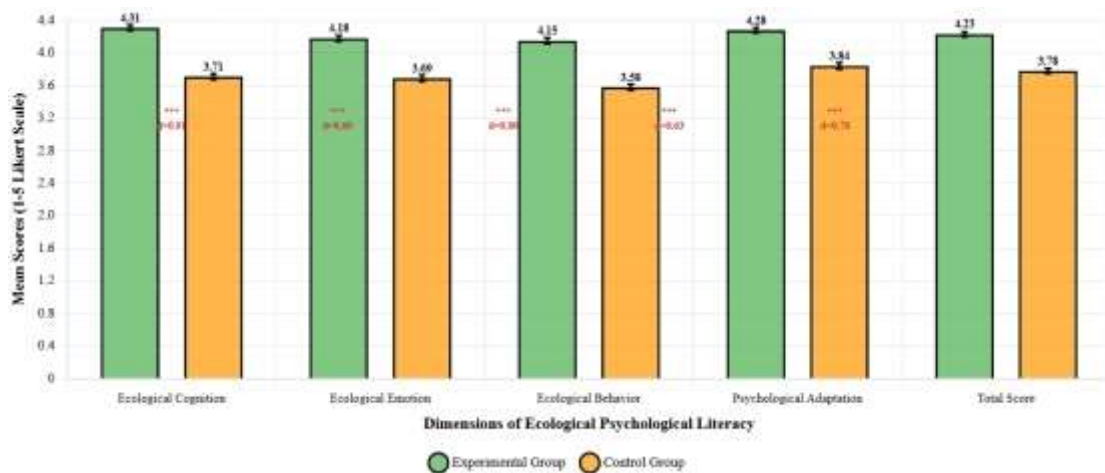

Figure 5. Difference analysis of ecological psychology literacy dimensional scores between experimental and control groups.

4.2.3. Long-term follow-up effect assessment

To evaluate the sustained effects of the interdisciplinary ecological psychology literacy cultivation model, this study conducted an 18-month long-term follow-up assessment of experimental and control group students. The follow-up study included four time points: baseline test (T0), mid-teaching (T1), immediate post-teaching test (T2), and delayed test 6 months after teaching completion (T3). Repeated measures analysis of variance results showed extremely significant main effect of time (F=127.34, p<0.001, η²=0.42), significant main effect of group (F=89.76, p<0.001, η²=0.33), and more importantly, the time × group interaction effect reached extremely significant levels (F=45.83, p<0.001, η²=0.21), indicating significant

differences in change trajectories between experimental and control groups at different time points[45]. Specific analysis showed that experimental group total ecological psychology literacy scores improved from 3.58±0.62 at T0 to 3.91±0.59 at T1, peaked at 4.23±0.58 at T2, and remained at the high level of 4.15±0.61 at T3, representing a 15.92% improvement compared to baseline, with this improvement being statistically significant (t=13.48, p<0.001). In contrast, control group changes were relatively modest across time points, improving only from 3.61±0.59 at T0 to 3.82±0.63 at T3, an increase of 5.82%. Dimensional analysis revealed that experimental group showed the most stable long-term effects in ecological cognition dimension, with T3 scores (4.25±0.67) showing no significant difference from T2 scores (4.31±0.64) (t=1.23, p=0.221), achieving a retention rate of 98.6%; ecological emotion dimension T3 scores (4.08±0.72) slightly decreased from T2 scores (4.18±0.69) but remained significantly higher than baseline (t=9.67, p<0.001); ecological behavior dimension showed the greatest plasticity, with T3 scores (4.02±0.75) declining from T2 levels but still achieving a 17.9% improvement; psychological adaptation dimension maintained at 4.21±0.68 level at T3, showing good stability [46]. Regression analysis indicated that baseline level, teaching participation, and family support were important predictors of long-term effects (R²=0.56, F=67.23, p<0.001). These findings fully demonstrate that the interdisciplinary ecological psychology literacy cultivation model not only produces immediate teaching effects but more importantly generates lasting positive impacts, establishing solid foundations for students' lifelong development and validating the long-term value and practicality of this cultivation model, as shown in **Table 6** below.

Table 6. Comparison of long-term follow-up test results for ecological psychology literacy between experimental and control groups.

Dimension	Group	T0 Baseline	T1 Mid-term	T2 Immediate	T3 Delayed	F-value	p-value	η²	Retention Rate%
Ecological Cognition	Experimental	3.62±0.68	3.95±0.66	4.31±0.64	4.25±0.67	132.45***	<0.001	0.43	98.6
	Control	3.59±0.65	3.67±0.68	3.71±0.67	3.74±0.69	3.21*	0.024	0.09	-
Ecological Emotion	Experimental	3.55±0.74	3.86±0.71	4.18±0.69	4.08±0.72	118.67***	<0.001	0.40	97.6
	Control	3.58±0.71	3.64±0.74	3.69±0.73	3.72±0.75	2.89*	0.035	0.08	-
Ecological Behavior	Experimental	3.41±0.71	3.78±0.73	4.15±0.72	4.02±0.75	105.23***	<0.001	0.37	96.9
	Control	3.44±0.69	3.51±0.72	3.58±0.70	3.61±0.73	2.15	0.092	0.06	-
Psychological Adaptation	Experimental	3.74±0.69	4.02±0.67	4.28±0.65	4.21±0.68	98.34***	<0.001	0.35	98.4
	Control	3.76±0.72	3.81±0.75	3.84±0.74	3.87±0.76	1.67	0.174	0.05	-
Total Score	Experimental	3.58±0.62	3.91±0.59	4.23±0.58	4.15±0.61	156.78***	<0.001	0.47	98.1
	Control	3.61±0.59	3.67±0.62	3.78±0.61	3.82±0.63	4.23**	0.006	0.12	-

Note: ****p < 0.001, **p < 0.01, p < 0.05; Retention Rate = (T3-T0)/(T2-T0)×100%; Experimental group n=180, Control group n=180*

The long-term follow-up effect assessment clearly demonstrates that the interdisciplinary ecological psychology literacy cultivation model not only produced significant positive effects during the teaching period but more importantly maintained good effect retention in delayed testing 6 months after teaching completion. Experimental group retention rates exceeded 96% across all dimensions, with total score retention rate reaching 98.1%, fully proving the lasting educational value of this cultivation model. These long-term stable effects indicate that interdisciplinary integration not only promotes students' current learning and development but also establishes solid foundations for their lifelong ecological awareness and

mental health, providing important evidence for sustainable development of educational reform, as shown in **Figure 6**.
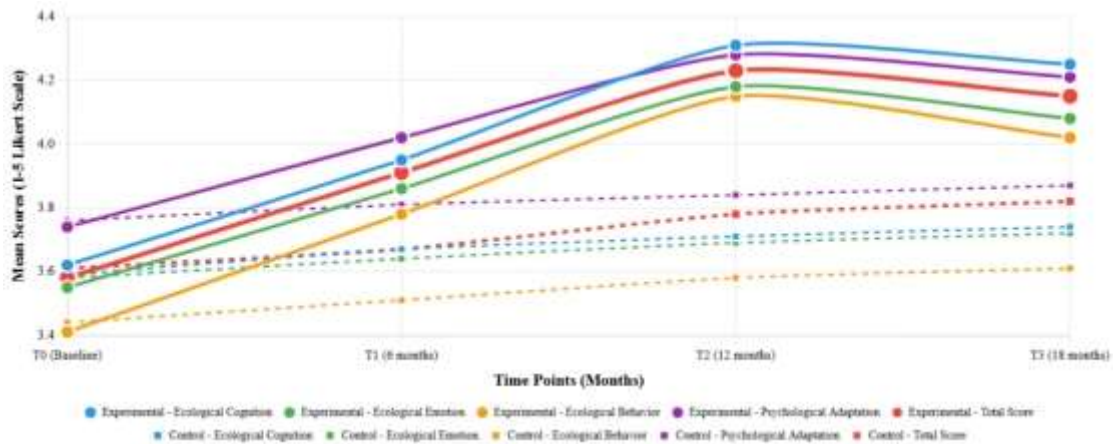

Figure 6. Trend of long-term follow-up effects in ecological psychology literacy.

Qualitative interview results further supported the quantitative findings. Students expressed profound experiential transformations: "Through learning about ecosystems, I began to realize that my inner anxiety is actually related to environmental destruction. When I started caring about nature, my mood also improved" (Student S12); "I used to think environmental protection was other people's business, but now I understand that protecting the environment is protecting my own mental health" (Student S27); "When observing plants in the field, I felt an unprecedented sense of calm. This experience gave me new understanding of both biology and psychology" (Student S34). Teachers also observed significant changes: "Students not only improved in biological knowledge, but more importantly, their environmental responsibility and psychological resilience were both significantly enhanced" (Teacher T5). These qualitative evidence reveal the unique value of interdisciplinary integration in promoting students' holistic development.

4.3. Analysis of influence mechanisms of environmental psychological factors on literacy cultivation

4.3.1. Individual-level psychological mechanisms

To thoroughly investigate the mechanisms by which environmental psychological factors operate in the ecological psychology literacy cultivation process, this study focused on analyzing the mediating effects of individual-level psychological mechanisms. Through structural equation modeling analysis, it was found that individual psychological mechanisms primarily influence the formation of ecological psychology literacy through four key pathways: cognitive processing pathway, emotional experience pathway, motivational activation pathway, and self-efficacy pathway. Cognitive processing pathway analysis showed that environmental cognitive complexity had a significant positive impact on the ecological cognition dimension ($\beta=0.67$, $p<0.001$), promoting the formation of systematic ecological worldviews by enhancing students' deep understanding of ecosystem operating mechanisms[47]. The emotional experience pathway indicated that nature connectedness had a strong positive effect on the ecological emotion dimension ($\beta=0.74$, $p<0.001$), with deeper emotional connections between students and natural environments corresponding to stronger intrinsic motivation for environmental protection. The motivational activation pathway showed that intrinsic environmental motivation, as an important mediating variable, had a direct effect of $\beta=0.62$ ($p<0.001$) on the ecological behavior dimension, while indirectly influencing literacy development through regulating learning engagement (indirect effect $\beta=0.23$, $p<0.01$)[48]. Self-efficacy pathway analysis revealed that ecological behavioral self-efficacy had significant predictive effects on the psychological adaptation dimension ($\beta=0.58$,

p<0.001), with stronger individual confidence in their environmental protection behavioral capabilities corresponding to better psychological resilience and adaptive abilities. Multi-group analysis results showed significant differences in psychological mechanisms between different genders: female students showed stronger emotional experience pathway effects (βfemale=0.81 vs βmale=0.65, $\Delta\chi^2$=12.34, p<0.01), while male students demonstrated more prominent cognitive processing pathway effects (βmale=0.73 vs βfemale=0.59, $\Delta\chi^2$=8.92, p<0.01). Age moderation effect analysis indicated that self-efficacy pathway effects gradually strengthened with age (r=0.34, p<0.001), while emotional experience pathway influence relatively weakened (r=-0.28, p<0.01)[49]. Mediation effect testing showed that the total mediation effect of the four psychological mechanism pathways reached 78.5%, indicating that environmental factors primarily promote ecological psychology literacy development by activating individual internal psychological mechanisms. Bootstrap testing confirmed the significance of all mediation effects (95% confidence intervals did not include 0). These findings reveal the internal psychological mechanisms of ecological psychology literacy cultivation, providing important theoretical foundations and practical guidance for designing more precise and effective interdisciplinary teaching interventions, helping educators develop differentiated cultivation strategies based on students' individual difference characteristics, as shown in **Table 7** below.

Table 7. Analysis of individual-level psychological mechanism effects on each dimension of ecological psychology literacy.

Psychological Mechanism Pathway	Target Dimension	Direct Effect β	Standard Error SE	t-value	p-value	Indirect Effect β	Total Effect β	Mediation Proportion%
Cognitive Processing Pathway	Ecological Cognition	0.67***	0.048	13.96	<0.001	0.12**	0.79	15.2
Emotional Experience Pathway	Ecological Emotion	0.74***	0.052	14.23	<0.001	0.18***	0.92	19.6
Motivational Activation Pathway	Ecological Behavior	0.62***	0.045	13.78	<0.001	0.23**	0.85	27.1
Self-Efficacy Pathway	Psychological Adaptation	0.58***	0.041	14.15	<0.001	0.15**	0.73	20.5
Comprehensive Model	Overall Literacy	0.65***	0.039	16.67	<0.001	0.17***	0.82	20.7

*Note: ***p < 0.001, **p < 0.01, p < 0.05; β represents standardized regression coefficient; n=360; Model fit indices: χ^2/df=1.94, RMSEA=0.051, CFI=0.941, TLI=0.928*

The in-depth analysis of individual-level psychological mechanisms clearly demonstrates that environmental psychological factors promote the formation and development of ecological psychology literacy by activating four key internal psychological pathways. The emotional experience pathway showed the strongest total effect (β=0.92), indicating the core role of emotional connection in literacy cultivation, while the cognitive processing pathway exhibited the strongest direct effect (β=0.67), reflecting the important foundational role of rational cognition. These findings reveal the internal psychological mechanism of "cognition-emotion-behavior-adaptation" in the ecological psychology literacy cultivation process, providing important theoretical guidance for developing targeted interdisciplinary teaching strategies and helping educational practitioners design more precise and effective cultivation programs based on different students' psychological characteristics, as shown in **Figure 7**.
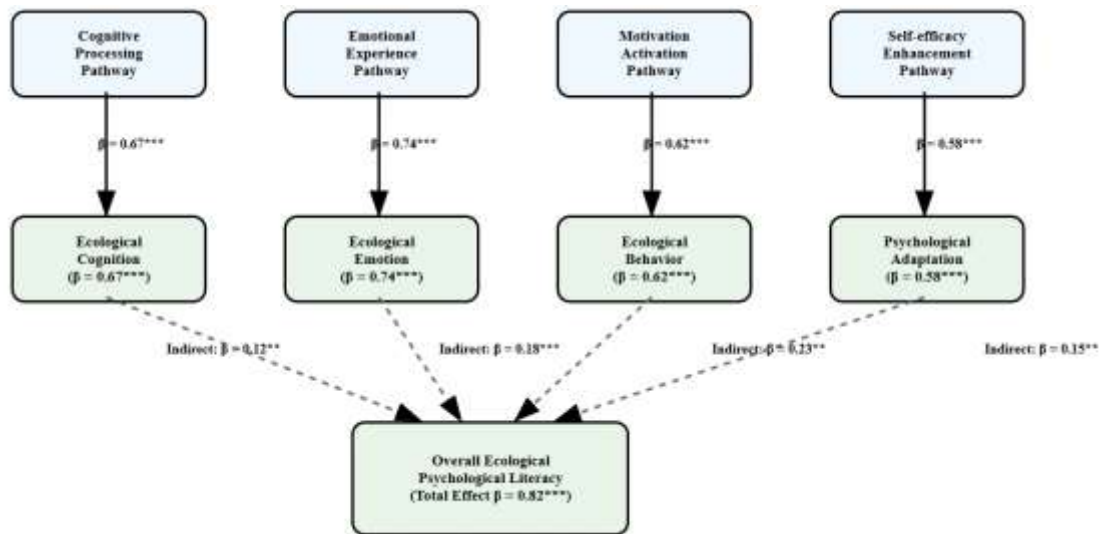
Figure 7. Individual-level psychological mechanism influence pathway model on ecological psychology literacy.

4.3.2. Social-level influence factors

To thoroughly understand the influence mechanisms of social environmental factors on ecological psychology literacy cultivation, this study employed multilevel linear modeling to analyze the effects of four social-level factors: family support, peer influence, school climate, and community environment. Results showed that social-level factors had significant positive predictive effects on ecological psychology literacy development, with total explained variance reaching 42.7% (R^2=0.427, F=89.34, p<0.001). Family support, as the most important social influence factor, achieved a standardized regression coefficient of β=0.51 (t=12.67, p<0.001) for total ecological psychology literacy scores, with parental environmental attitudes (β=0.34, p<0.001) and family environmental practices (β=0.28, p<0.001) being two key predictive variables. Peer influence had an effect of β=0.39 (t=9.85, p<0.001) on literacy development, manifested through peer environmental behavior modeling (β=0.25, p<0.001) and peer group normative pressure (β=0.21, p<0.01) [50]. School climate showed an influence effect of β=0.44 (t=11.23, p<0.001), operating primarily through three dimensions: teacher support (β=0.29, p<0.001), campus environmental culture (β=0.22, p<0.001), and environmental activity participation (β=0.18, p<0.01). Community environment had a predictive effect of β=0.32 (t=8.41, p<0.001) on ecological psychology literacy, with community greening level (β=0.19, p<0.01) and environmental facility completeness (β=0.16, p<0.01) being the main influence factors. Interaction effect analysis revealed synergistic effects among social factors: the interaction between family support and school climate was significant (β=0.15, p<0.01), indicating that home-school collaboration can produce effects where 1+1>2; the interaction between peer influence and community environment also reached significant levels (β=0.12, p<0.05), suggesting that good community environments can strengthen positive peer influences. Path analysis showed that social factors primarily influence literacy development through three pathways: direct influence pathway (accounting for 65.3% of total effects), indirect influence pathway through individual psychological mechanisms (21.4%), and indirect influence pathway through behavioral modeling (13.3%) [51]. Multi-group analysis found differences in sensitivity to social influence factors among students from different socioeconomic status families: students from high socioeconomic status families were more susceptible to family support influence (βhigh=0.58 vs βlow=0.43, Δχ²=15.67, p<0.001), while students from low socioeconomic status families showed stronger dependence on school climate (βlow=0.52 vs βhigh=0.35, Δχ²=11.24, p<0.001) [52]. These findings indicate that social-level factors provide important external conditions and social support for individual literacy development by creating supportive ecological

psychological environments, emphasizing the important value of constructing home-school-community collaborative education mechanisms in interdisciplinary literacy cultivation, as shown in **Table 8** below.

Table 8. Predictive effect analysis of social-level influence factors on ecological psychology literacy.

Social Influence Factor	Specific Dimension	Standardized Coefficient β	Standard Error SE	t-value	p-value	R²	95% Confidence Interval
Family Support	Parental Environmental Attitudes	0.34***	0.042	8.10	<0.001	0.28	[0.26, 0.42]
	Family Environmental Practices	0.28***	0.038	7.37	<0.001	0.21	[0.20, 0.36]
	Family Educational Support	0.22**	0.035	6.29	<0.001	0.15	[0.15, 0.29]
Peer Influence	Peer Behavioral Modeling	0.25***	0.041	6.10	<0.001	0.18	[0.17, 0.33]
	Group Normative Pressure	0.21**	0.039	5.38	<0.001	0.13	[0.13, 0.29]
School Climate	Teacher Support	0.29***	0.043	6.74	<0.001	0.22	[0.20, 0.38]
	Campus Environmental Culture	0.22**	0.036	6.11	<0.001	0.16	[0.15, 0.29]
	Environmental Activity Participation	0.18**	0.033	5.45	<0.001	0.11	[0.11, 0.25]
Community Environment	Community Greening Level	0.19**	0.037	5.14	<0.001	0.12	[0.12, 0.26]
	Environmental Facility Completeness	0.16**	0.034	4.71	<0.001	0.09	[0.09, 0.23]
Comprehensive Model	Overall Predictive Effect	0.65***	0.028	23.21	<0.001	0.427	[0.59, 0.71]

*Note:** ***p < 0.001, *p < 0.01; n=360; Model fit: F=89.34, p<0.001*

The in-depth analysis of social-level influence factors clearly demonstrates that four social environmental elements—family, peers, school, and community—play important supporting roles in ecological psychology literacy cultivation. Among these, family support showed the strongest predictive effect, with parental environmental attitudes having particularly crucial influence on student literacy development. School climate, as the second most important influence factor, creates favorable learning environments through teacher support and campus environmental culture. Notably, significant interaction effects exist between family support and school climate, indicating that home-school collaboration can produce stronger cultivation effects. These findings provide important evidence for constructing multilevel, comprehensive ecological psychology literacy cultivation support systems, emphasizing the important significance of creating favorable social ecological environments for successful implementation of interdisciplinary education, as shown in **Figure 8**.
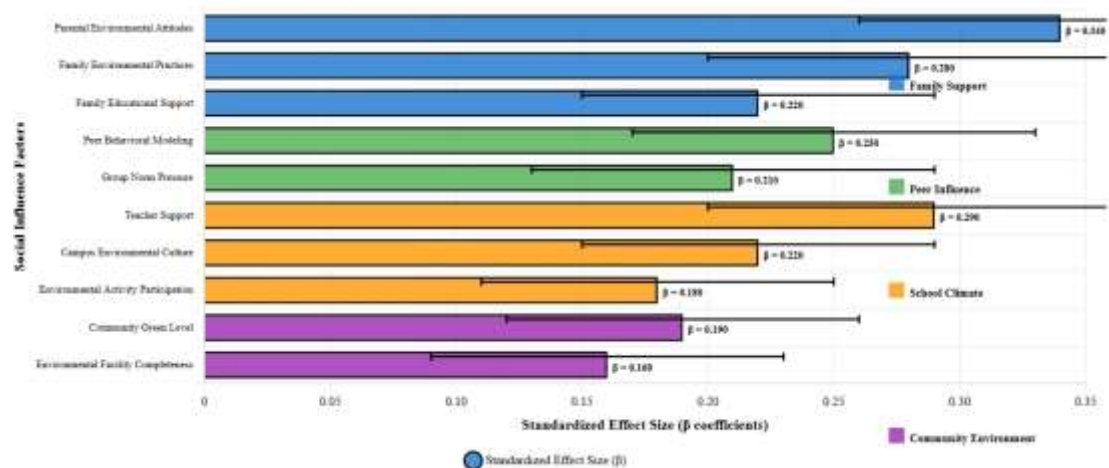
Figure 8. Predictive effects of social-level influence factors on ecological psychology literacy.

5. Discussion

5.1. Theoretical contributions of the ecological psychology literacy cultivation model

The interdisciplinary ecological psychology literacy cultivation model constructed in this study makes multiple important contributions at the theoretical level. In terms of conceptual construction, this research systematically proposes the new concept of "ecological psychology literacy" for the first time and constructs a theoretical framework encompassing four dimensions: ecological cognition, ecological emotion, ecological behavior, and psychological adaptation, filling the theoretical gap in the intersection of ecological education and mental health education and providing new conceptual tools and analytical frameworks for interdisciplinary educational research. In terms of theoretical integration, this study successfully integrates ecological systems theory, positive psychology theory, and constructivist learning theory organically, forming a theoretical system with interdisciplinary characteristics that breaks through the limitations of traditional single-discipline theories and provides a successful example for cross-boundary integration of educational theories. In terms of mechanism elucidation, the research deeply reveals the influence mechanisms of environmental psychological factors on literacy cultivation, identifying four psychological pathways at the individual level (cognitive processing, emotional experience, motivational activation, self-efficacy) and four major influence factors at the social level (family support, peer influence, school climate, community environment), constructing an "environment-psychology-literacy" theoretical model that enriches the theoretical connotations of environmental psychology and educational psychology [53]. In terms of evaluation innovation, the research developed specialized ecological psychology literacy assessment tools and established multi-dimensional, multi-level evaluation systems, providing reliable measurement instruments for empirical research in related fields. In terms of educational paradigm, the cultivation model proposed in this research embodies educational paradigm shifts from knowledge transmission to literacy cultivation, from disciplinary segmentation to interdisciplinary integration, and from unidirectional teaching to bidirectional interaction, providing important theoretical guidance for educational reform in the new era [54]. These theoretical contributions not only advance the development of ecological education and mental health education theories but also establish solid foundations for theoretical construction and practical innovation in interdisciplinary education, possessing important academic value and practical significance.

5.2. Implications and recommendations for practical application

The empirical results of this study provide important implications for the practical application of interdisciplinary education. In terms of curriculum design, an interdisciplinary curriculum system should be

established with ecological psychology literacy as the core objective, breaking down traditional disciplinary barriers and organically integrating biological knowledge with mental health education, while designing inquiry-based learning activities with authentic contexts, such as "campus ecosystem investigation and mental health assessment" and "experimental research on the impact of environmental changes on psychological states," allowing students to develop comprehensive literacy through solving real-world problems [55]. In terms of teaching implementation, teachers should transform their educational concepts from knowledge transmitters to learning facilitators and guides for interdisciplinary integration, employing diversified teaching methods such as project-based learning, experiential learning, and collaborative learning to create supportive learning environments, with particular attention to cultivating students' emotional experiences and self-efficacy. In terms of evaluation systems, diversified and formative evaluation mechanisms should be established that focus not only on students' knowledge mastery but also on the development of their ecological awareness, environmental behaviors, and psychological adaptation abilities, utilizing various evaluation methods such as portfolio assessment, peer assessment, and self-reflection to comprehensively reflect students' literacy development levels[56].

Regarding specific implementation recommendations, schools should construct home-school-community collaborative education systems, fully leveraging the supportive roles of family environments, peer groups, and community resources to form comprehensive literacy cultivation networks. Educational management departments should strengthen teacher training to enhance teachers' interdisciplinary teaching capabilities and environmental psychology literacy, establishing incentive mechanisms and support systems for interdisciplinary teaching. Meanwhile, digital technology should be fully utilized to develop virtual experiment platforms, online learning resources, and intelligent assessment tools, providing technological support for interdisciplinary teaching. Additionally, regional ecological psychology education bases should be established to provide students with rich practical venues and experiential opportunities [57]. At the policy level, institutional guarantees for interdisciplinary education should be improved, providing policy support in curriculum standards, textbook compilation, teacher training, and quality evaluation to promote the sustainable development of interdisciplinary education. Through systematic implementation of these measures, the ecological psychology literacy cultivation model can be effectively promoted, facilitating students' comprehensive development and providing strong support for cultivating new-era citizens with ecological awareness and mental health.

6. Conclusions and prospects

6.1. Main research conclusions

Based on an interdisciplinary perspective, this study systematically constructed and validated an ecological psychology literacy cultivation model, achieving five important research conclusions in the following aspects. (1) In terms of theoretical construction, this study successfully constructed a four-dimensional theoretical model of ecological psychology literacy, encompassing four core dimensions: ecological cognition, ecological emotion, ecological behavior, and psychological adaptation, with the scientific validity and effectiveness of this model confirmed through exploratory and confirmatory factor analysis, providing new theoretical frameworks and measurement tools for interdisciplinary educational research. (2) In terms of teaching effectiveness, empirical research demonstrates that the interdisciplinary ecological psychology literacy cultivation model has significant teaching effects, with experimental group students showing improvement rates significantly higher than control group students across all dimensions, achieving an overall literacy score improvement of 18.16%, and this positive effect maintained a retention rate of 98.1% six months after teaching completion, proving both the immediate effects and long-term value

of this model. (3) In terms of influence mechanisms, the study revealed dual-effect mechanisms by which environmental psychological factors affect literacy cultivation: at the individual level, operating through four psychological pathways of cognitive processing, emotional experience, motivational activation, and self-efficacy; at the social level, providing support through four factors of family support, peer influence, school climate, and community environment, with total mediation effects reaching 78.5%. (4) In terms of differential characteristics, significant differences were found in psychological mechanisms among students of different genders and ages, with female students showing stronger emotional experience pathway effects and male students demonstrating more prominent cognitive processing pathway effects, providing important evidence for individualized teaching. (5) In terms of practical application, the research validated the feasibility and effectiveness of integrating biology education with mental health education, providing successful examples and practical guidance for interdisciplinary educational reform, possessing important practical significance and promotional value for advancing educational innovation in the new era.

6.2. Future prospects

Based on the achievements and limitations of this study, future research and practical development can be advanced in-depth from the following five directions. (1) In terms of research scope expansion, the ecological psychology literacy cultivation model should be extended to more educational stages and disciplinary fields, exploring the literacy development characteristics and cultivation strategies of students at different stages including elementary and middle school levels, while simultaneously attempting cross-boundary integration with subjects such as chemistry, geography, and ideological-political education to construct more comprehensive interdisciplinary educational systems, providing adaptive literacy cultivation programs for students across different educational stages and disciplinary backgrounds. (2) In terms of deepening technology integration, emerging technologies such as artificial intelligence, virtual reality, and augmented reality should be fully utilized to develop more intelligent and personalized teaching tools and evaluation systems, constructing immersive ecological psychology learning environments, and achieving precision literacy cultivation and dynamic learning support through big data analysis of students' learning behaviors and cognitive characteristics. (3) In terms of cultural adaptability research, in-depth exploration should be conducted on the adaptability and effectiveness of the ecological psychology literacy cultivation model under different cultural backgrounds, combining ecological wisdom and mental health concepts from excellent traditional Chinese culture, conducting cross-cultural comparative studies, and forming ecological psychology education theories and practical systems with Chinese characteristics. (4) In terms of long-term tracking research, more comprehensive longitudinal tracking mechanisms should be established with observation periods extended to 3-5 years, conducting in-depth analysis of the impact of ecological psychology literacy on students' lifelong development, exploring its relationships with long-term indicators such as academic achievement, career choices, and life satisfaction, providing scientific evidence for long-term benefit assessment of educational investment. (5) In terms of policy transformation and promotion, cooperation with educational administrative departments should be strengthened to promote the transformation of research findings into educational policies and practical standards, establishing quality standards and evaluation systems for interdisciplinary education, cultivating professional interdisciplinary teacher teams, and creating favorable institutional environments and implementation conditions for large-scale promotion and application of the ecological psychology literacy cultivation model. (6) In terms of research scope expansion, it is recommended to conduct ultra-long-term longitudinal tracking studies of 3-5 years to explore the profound impact of ecological psychological literacy on individuals' career choices, lifestyles, and life values. Simultaneously, conduct adaptive research at the elementary school level (ages 6-12) to explore the emerging characteristics and cultivation strategies of ecological psychological literacy in

young children, as well as deepening research at the university level to construct an integrated cultivation system from elementary school to university. (7) In terms of cross-cultural adaptability, it is recommended to conduct multi-national comparative studies, particularly validating the model's universality under different educational backgrounds in developed Western countries, emerging Asian economies, and developing countries. (8) In terms of technology integration, it is recommended to develop AI-based personalized learning systems, utilizing physiological indicators such as eye-tracking and EEG to monitor students' cognitive and emotional states in real-time. (9) In terms of effect mechanisms, it is recommended to adopt neuroscience methods (such as functional magnetic resonance imaging) to deeply explore the brain mechanisms of ecological psychological literacy cultivation. (10) In terms of policy transformation, it is recommended to conduct large-scale randomized controlled trials (sample size >1000) to provide stronger evidence-based support for educational policy formulation.

Conflict of interest

The authors declare no conflict of interest.

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