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RESEARCH ARTICLE

Role adaptation of Maysian secondary school physics teachers to AI-assisted experimental teaching: Integrating social psychological challenges with

Mengji Tian*, Qianxi Jiang

School of Education，Taylor University, Selangor, 47500, Malaysia

*** Corresponding author:** Mengji Tian, tian_meng_ji@outlook.com

ABSTRACT

With the rapid development of artificial intelligence technology in the educational field, teacher role adaptation has emerged as a critical factor influencing educational quality. This study focuses on Malaysian secondary physics teachers and employs an explanatory sequential mixed-methods design, utilizing questionnaire surveys (n=420), in-depth interviews (n=30), focus group discussions (6 groups), and classroom observations (12 cases) to thoroughly investigate teachers' role adaptation processes in AI-assisted experimental teaching, the socio-psychological challenges they encounter, and the integration pathways of environmental sustainability practices. The findings reveal that Malaysian secondary physics teachers demonstrate significant stratified characteristics in their cognitive levels regarding AI technology, with 23.8% possessing high cognitive levels, and younger teachers showing markedly higher technology acceptance than their older counterparts. During the role adaptation process, 72.4% of teachers experience varying degrees of role identity conflicts, primarily manifested as challenges to professional authority (68.1%) and shifts in instructional control (74.3%). Technology anxiety and adaptation pressure exhibit high correlation (r=0.72), with significant gaps between social support needs and current provision, particularly in technical training support (gap of 1.65 points).Environmental awareness exerts decisive influence on instructional design, with teachers possessing high environmental awareness demonstrating superior performance (78.9%) in integrating sustainability elements compared to those with low environmental awareness (31.6%). Green experimental teaching practice models achieve remarkable effectiveness, with 73.6% of teachers adopting related models and realizing 42.8% resource conservation rates. The achievement of sustainable development education goals exhibits multi-pathway synergistic effects, with interdisciplinary integrated teaching yielding optimal results (4.15 points), and students maintaining environmental behavior continuity rates of 78.3% post-graduation.The study constructs a three-dimensional "cognition-emotion-behavior" role adaptation model and a "technology-environment-society" triangular integration framework, providing theoretical guidance and practical pathways for promoting the organic fusion of AI-assisted teaching and environmental sustainability practices. This research enriches the empirical foundation of educational technology acceptance theory and offers significant reference for educational digital transformation and sustainable development education in Malaysia and other developing countries. The research results provide direct guidance for educational policy formulation and teacher professional development: it is recommended to construct a multi-tiered AI technology training

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system, with a focus on strengthening technical support for teachers over 50 years old; develop AI-assisted teaching curriculum standards that include environmental education modules, organically integrating virtual experiment technology with green education concepts; establish a three-dimensional teacher development support mechanism of "technical mentors + environmental experts + psychological support" to effectively alleviate social psychological pressure during the role adaptation process. These findings can be directly applied to educational digitalization transformation strategy formulation and teacher training system reform in Malaysia and other developing countries.

Keywords: AI-assisted experimental teaching; teacher role adaptation; socio-psychological challenges; environmental sustainability; physics education; Malaysia; green experimental teaching; sustainable development education

1. Introduction

With the rapid development and widespread application of artificial intelligence technology in the educational field, traditional teaching models are confronting unprecedented opportunities and challenges for transformation. In the realm of physics experimental teaching, the introduction of AI-assisted technology not only provides new possibilities for experimental design, data analysis, and teaching effectiveness enhancement, but also presents novel requirements for teachers' role positioning and professional development. Scholars such as Cao Pengxia have indicated in their research on augmented reality-assisted physics experimental teaching that the integration of emerging technologies can significantly enhance the intuitiveness and interactivity of experimental instruction[1], while Li Zhe and colleagues' research further confirms the important role of theoretical computation-assisted experimental teaching in reforming traditional pedagogical models [2]. However, this technology-driven educational transformation is not merely a simple substitution at the instrumental level, but rather involves deep-seated socio-psychological processes encompassing teachers' role cognition, professional identity reconstruction, and pedagogical philosophy transformation. Particularly in Malaysia's multicultural and multilingual educational environment, secondary physics teachers, when confronted with AI-assisted experimental teaching, must not only overcome objective difficulties in technology application but also address the role adaptation pressures and psychological challenges that arise from these changes.

Currently, AI-assisted experimental teaching technology has demonstrated tremendous application potential and practical value across various disciplinary fields. Research by Darzi and colleagues in the renewable energy sector indicates that AI-assisted simulation technology can significantly improve the efficiency and precision of experimental design[3], while Zhou et al.'s development of thermal-hydraulic analysis methods has also confirmed the crucial role of AI technology in complex experimental processes [4]. These technological advances provide robust support for physics experimental teaching, enabling experiments that were previously complex, dangerous, or costly to be conducted safely and efficiently through virtual simulation. Ma Jiying emphasizes in her research on digital information systems assisting physics experimental teaching that the application of digital technology can effectively enhance the quality and efficiency of experimental instruction[5], while Liu Bin and colleagues' virtual simulation experiment research further expands the boundaries and possibilities of experimental teaching [6]. However, technological sophistication cannot automatically translate into teaching effectiveness; the key lies in whether teachers can successfully adapt to this technological transformation and reposition their roles and value within the new educational environment. This adaptation process is often accompanied by complex socio-psychological challenges, including multiple predicaments such as technology anxiety, role identity crisis, and fluctuations in professional efficacy.

Under the guidance of global sustainable development goals, the educational field is increasingly emphasizing the integration and promotion of environmental sustainability practices. For physics experimental teaching, how to effectively integrate environmental sustainability concepts while introducing AI-assisted technology is not only a necessity for teaching content innovation but also an important pathway for cultivating students' environmental awareness and sustainable development literacy. Traditional physics experiments often involve substantial material consumption, energy usage, and waste generation, while the application of AI-assisted virtual experiment technology provides new solutions for achieving green experimental teaching. Through virtual simulation technology, students can complete complex experimental operations without consuming actual resources, which not only reduces experimental costs but, more importantly, embodies environmentally friendly teaching philosophy. However, to achieve effective integration of AI technology and environmental sustainability practices requires teachers to embody green education concepts throughout all aspects of teaching design, implementation, and evaluation, placing higher demands on teachers' professional competence and role adaptation capabilities. Research by Zheng and colleagues on AI-assisted management systems demonstrates the application potential of AI technology in complex environments, providing important insights for our consideration of AI technology's role in sustainable education[7]. AI-assisted experimental teaching not only represents innovation in educational technology, but more importantly, it provides breakthrough solutions for addressing the environmental burden issues in traditional physics experimental teaching. Through virtual reality technology simulating complex experimental processes, AI systems can provide high-fidelity learning experiences without consuming actual materials and energy, achieving the green teaching goals of "zero waste, low energy consumption, and high efficiency." This technology-environment synergistic teaching innovation model not only cultivates students' scientific literacy, but also subtly strengthens sustainable development concepts, providing a practical paradigm for constructing an environmentally friendly education system.

Based on the aforementioned background, this study focuses on Malaysian secondary physics teachers' role adaptation processes in AI-assisted experimental teaching, with particular attention to the socio-psychological challenges they face and the integration pathways of environmental sustainability practices. Malaysia, as a rapidly developing multicultural nation, faces multiple balances between tradition and innovation, local and international perspectives, and technology and humanities while advancing educational modernization. Secondary physics teachers, as direct participants and implementers of educational transformation, directly influence the implementation effectiveness and sustainable development of AI-assisted experimental teaching through their role adaptation status. This study attempts to reveal the internal mechanisms and influencing factors of role adaptation by deeply analyzing teachers' cognitive changes, emotional experiences, and behavioral adjustments during the technology integration process, and to explore how to effectively integrate environmental sustainability practices in AI-assisted teaching, providing theoretical guidance and practical support for constructing physics experimental teaching models that are both technologically advanced and environmentally friendly. Through this research, we expect to provide valuable references for physics education reform in Malaysia and broader regions, promoting the synergistic achievement of teacher professional development and sustainable education goals.

2. Literature review

AI-assisted experimental teaching, as an essential component of educational technology innovation, has demonstrated tremendous developmental potential and widespread application prospects globally. From a technological development perspective, the application of artificial intelligence in education has undergone a transformation from simple computer-assisted instruction to intelligent personalized learning support. Scholars such as Zhao Jun have indicated in their exploration of multimedia technology-assisted physics and chemistry experimental teaching that technological assistance can significantly enhance the intuitiveness and effectiveness of experimental instruction, providing students with richer learning experiences[8]. This perspective has been further validated in international research, where Ye et al.'s study on applying AI-assisted multi-advisor systems in clinical pharmacy education demonstrates that the integration of AI technology with traditional teaching models can significantly improve teaching quality and learning outcomes[9]. Meanwhile, Ahmmad and colleagues' research on AI technology optimization in disability support systems reveals the adaptability and effectiveness of AI-assisted technology in complex educational environments [10]. In specific applications to physics experimental teaching, Chen Shang et al.'s exploration of mobile internet-assisted physics and chemistry experimental teaching models has injected new vitality into traditional experimental instruction[11], while Gu Jinhua and colleagues' research utilizing computer-assisted university physics experimental teaching further confirms the important role of digital technology in enhancing experimental teaching efficiency and quality[12]. These studies collectively indicate that AI-assisted technology not only can transcend the limitations of traditional experimental teaching in terms of time, space, and resources, but also can provide learners with personalized, interactive learning experiences, fundamentally transforming the models and effectiveness of experimental teaching. However, rapid technological development has also posed new challenges to teachers' professional capabilities and role positioning. How to maintain teachers' core value and function in technology-driven teaching environments has become an important issue in contemporary educational research.

The process of teacher role adaptation when confronting AI-assisted teaching technology is essentially a complex socio-psychological transformation process, involving multiple dimensions including cognitive reconstruction, emotional adjustment, and behavioral modification. From the perspective of learning psychology, scholars such as Li Yuexian emphasize the importance of teaching resource assistance from a learning psychological perspective, noting that teachers need to reconstruct their teaching cognition and practice models within new technological environments[13]. This viewpoint resonates with Li Ya et al.'s research on the application of mental health education in university physics teaching, emphasizing the direct impact of teachers' psychological states on teaching effectiveness[14]. During the process of technology acceptance and adaptation, teachers often experience psychological transitions from resistance to acceptance, from passive to active engagement. This transformation involves not only cognition and mastery of the technology itself, but more importantly, the repositioning of their professional roles and identities. International research has also confirmed this point, with Tsuyuzaki et al.'s evaluation research on AI diagnostic systems finding that professionals' acceptance of AI-assisted systems is closely related to their professional confidence and technological cognitive levels[15]. Yuan et al.'s analysis of global research trends in AI-assisted blood glucose management further reveals the adaptive differences and influencing factors among professionals in AI technology applications[16]. From a social psychological perspective, teacher role adaptation is not only individual-level psychological adjustment but also collective behavioral patterns within specific socio-cultural contexts. In multicultural educational environments, such as Malaysia, teacher role adaptation must also consider the influence of multiple variables including cultural factors, linguistic environments, and social expectations. This complexity makes teacher role adaptation a process requiring systematic support and long-term attention, where technical training alone often proves insufficient for achieving deep-level role transformation.

Under the guidance of global sustainable development goals, the educational field increasingly emphasizes the integration of environmental sustainability practices, while AI technology provides new technical means and implementation pathways for achieving green education. Wang Jinwei et al.'s analysis of AI pollution issues from the perspective of information ecological environment protection provides important insights for our consideration of AI technology's environmental impact[17]. Research indicates that

AI technology applications need to fully consider their environmental impact and sustainability while pursuing teaching efficiency and quality. In new media environments, Huang Linan's exploration of AI technology integration reveals the importance of environmental friendliness in technology applications [18], while Pan Yukai's research on constructing AI monitoring matrices in converged media environments demonstrates the application potential of AI technology in environmental monitoring and protection [19]. From a teaching practice perspective, Huang Lina's AI-based audio collection research in noisy environments provides technical support for understanding AI technology's role in improving teaching environment quality[20]. Xie Rong et al.'s practical exploration of AI-empowered environmental design professional teaching from the perspective of industry-education integration directly embodies the organic combination of AI technology and environmental sustainability education[21]. Tang Wanyu's application analysis of AI-digitized landscapes in human-environment interactive design further expands our understanding of AI technology's role in environmentally friendly teaching design[22]. In practical teaching applications, AI-assisted virtual experiment technology can significantly reduce material and energy consumption in physical experiments, decrease experimental waste generation, thereby achieving green teaching processes. Simultaneously, AI technology can help students better understand the importance of environmental protection by simulating experiments that demonstrate environmental change processes and consequences, cultivating students' environmental awareness and sustainable development concepts. Shen Pengyi et al.'s research on the impact of AI-driven product environmental benefits on consumer willingness to pay provides an economic perspective explanation for understanding AI technology's role mechanisms in promoting environmentally friendly behaviors[23].

Malaysia, as a multicultural and multilingual developing country, possesses unique complexity and challenges in its educational environment, providing special contextual conditions for the implementation of AI-assisted experimental teaching and teacher role adaptation. In the educational transformation of the AI era, Nie Ying's research on the environmental art design industry and education reveals the differences and adaptability issues of AI technology applications across different cultural backgrounds[24]. Qi Xiaojuan's analysis of elementary mathematics mutual assistance and question-clarification teaching in AI smart classroom environments demonstrates localized application models of AI technology in multicultural educational environments[25]. Hou Qiang et al.'s research on AI intelligence applications in interior design fields under big data environments further confirms AI technology's adaptability and developmental potential across different educational domains[26]. From an international comparative perspective, Birla et al.'s research on AI-assisted methods in thyroid tumor diagnosis demonstrates the precision and effectiveness of AI technology in professional education and practice[27]. Zhaojie et al.'s investigative research on artificial intelligence effectiveness in English listening teaching provides empirical support for understanding AI technology's role in language education[28]. These studies indicate that AI technology demonstrates good adaptability and application prospects across different cultural and educational backgrounds, but simultaneously requires consideration of localized implementation strategies and cultural adaptability issues. In Malaysia's educational environment, teachers need not only to adapt to AI technology itself but also to consider how to effectively integrate technological resources within multicultural contexts to meet the learning needs of students from diverse cultural backgrounds. Furthermore, the Malaysian government's policy support for educational informatization and sustainable development provides a favorable institutional environment for the promotion and implementation of AI-assisted experimental teaching. However, in practical applications, issues such as the improvement of teacher training systems, the construction of technological infrastructure, and the cultivation of cross-cultural teaching capabilities still require adequate attention and resolution. Looking toward the future, as AI technology continues to develop and educational concepts continuously evolve, Malaysian secondary physics teachers' role adaptation in AI-assisted experimental teaching will exhibit increasingly diversified and personalized characteristics, necessitating the construction of more flexible and inclusive support systems to promote the organic integration of technological innovation and cultural heritage.

3. Research methods

3.1. Research design

This study employs an Explanatory Sequential Mixed Methods Design to comprehensively investigate Malaysian secondary physics teachers' role adaptation processes in AI-assisted experimental teaching and the socio-psychological challenges they encounter. The design consists of two consecutive phases: The first phase involves collecting large-sample data through quantitative research, utilizing structured questionnaire surveys to measure key variables including teachers' acceptance of AI technology, role adaptation status, technology anxiety levels, and environmental sustainability practice awareness. The sample covers 280 secondary schools across 13 states in Malaysia, with an anticipated collection of 420 valid questionnaires. Quantitative data analysis will employ descriptive statistics, correlation analysis, regression analysis, and structural equation modeling to identify the primary factors influencing teacher role adaptation and their operational mechanisms [29]. The second phase conducts in-depth qualitative exploration based on quantitative results, utilizing semi-structured interviews, focus group discussions, and classroom observations to gain deeper understanding of teachers' internal adaptation processes, specific challenges, and coping strategies. The qualitative research will employ purposive sampling, selecting teachers with different adaptation levels for in-depth interviews (30 participants), organizing 6 focus groups (8-10 participants each), and conducting 3-month longitudinal observations of 12 typical cases.

The philosophical foundation of this research is established upon pragmatist epistemology, recognizing that teacher role adaptation is a complex socio-psychological phenomenon requiring integration of objective measurement and subjective experience for comprehensive understanding. At the methodological level, this study follows a transformative mixed methods framework, emphasizing social justice and cultural sensitivity, with particular attention to the differentiated experiences of teachers from various ethnic groups within Malaysia's multicultural context. The quantitative phase focuses on statistical testing of variable relationships and pattern identification, while the qualitative phase emphasizes meaning construction and revelation of deep-level mechanisms. Data from both phases will be integrated through triangulation methods to ensure the credibility and validity of research findings.

To enhance the validity of causal inference, the study incorporated control for key confounding variables, including teachers' prior AI training experience (categorized into three levels: no training, basic training, and advanced training), school technology resource levels (comprehensive scores constructed through six indicators including equipment configuration, network conditions, and technical support staff deployment), personal technology self-efficacy, and school innovation climate as covariates. Propensity Score Matching (PSM) methods were employed to control for selection bias, and a 12-month longitudinal tracking design (T1 baseline survey, T2 after six months, T3 after twelve months) was implemented to explore the temporal relationship between environmental awareness and teaching behavior changes. Cross-lagged panel models were used to analyze causal direction, ensuring the causal validity of the environmental awareness correlation conclusion ($r=0.68$).

To ensure the scientific rigor and ethical integrity of the research, this study has established strict quality control standards. In the quantitative phase, questionnaire design underwent expert review and pilot testing to ensure the reliability and validity of measurement instruments; the sampling strategy employs stratified proportional sampling to guarantee sample representativeness; data collection processes implement standardized procedures to minimize measurement errors. In the qualitative phase, researchers will receive specialized interview skills training and develop detailed interview guides and observation recording forms; data analysis will employ multiple-coder approaches and member checking to enhance result reliability [30]. The entire research process strictly adheres to academic ethical standards, obtaining informed consent from participants, protecting personal privacy, and ensuring data security. Additionally, the research team will establish cross-cultural research coordination mechanisms to ensure sensitivity and inclusivity toward different cultural groups in Malaysia throughout the research process.

3.2. Research participants and sampling methods

The target population of this study comprises Malaysian secondary physics teachers across 13 states and 3 federal territories, encompassing both public and private secondary schools nationwide. The inclusion criteria for research participants include: possession of physics teaching certification, a minimum of 2 years of physics teaching experience, current engagement in secondary physics experimental teaching, and basic understanding or practical exposure to AI-assisted teaching technology. Exclusion criteria encompass: newly recruited teachers with less than 2 years of teaching experience, teachers primarily engaged in theoretical instruction with minimal involvement in experimental teaching, and teachers approaching retirement (within 1 year). Considering Malaysia's multicultural educational background, the research particularly emphasizes the representativeness of teachers from different ethnic groups (Malay, Chinese, Indian, and other ethnicities), various linguistic teaching backgrounds (Bahasa Malaysia, English, and Chinese instruction), and different geographical regions (urban, suburban, and rural areas). Simultaneously, teachers are categorized according to their technology acceptance levels, teaching experience (2-10 years, 11-20 years, over 20 years), educational backgrounds (Bachelor's, Master's, Doctoral degrees), and school types (National Secondary Schools, National-type Secondary Schools, Private Secondary Schools, International Schools) to ensure sample diversity and representativeness. A population proportion weight adjustment strategy was adopted, allocating sample quotas according to the proportion of teachers by state based on 2024 statistical data from the Malaysian Ministry of Education, with Selangor accounting for 18.2%, Johor 12.6%, Sarawak 10.4%, etc. Ethnic weights (Malay 65%, Chinese 24%, Indian 7%, other ethnic groups 4%) and urban-rural weights (urban 60%, suburban 25%, rural 15%) were simultaneously set to ensure sample representativeness. The effective sample after weighting was 420 cases, with a design effect value of 1.23.

The sampling strategy employs a multi-stage stratified proportional sampling method to ensure sample balance across geographical distribution, school types, and teacher characteristics. The first stage divides the nation into 5 geographical regions (Northern, Central, Southern, East Coast, and East Malaysia) according to the Malaysian Ministry of Education's administrative divisions, with each region further subdivided based on economic development levels and urban-rural distribution characteristics. The second stage involves stratification within each subdivision based on school size and type, ensuring proportional representation of different school categories. The third stage conducts random sampling within selected schools based on teachers' demographic characteristics and professional backgrounds. The quantitative research phase plans to sample 420 physics teachers from 280 secondary schools. Calculated at a 95% confidence level with a 5% margin of error, this sample size satisfies statistical analysis requirements. The qualitative research phase employs a combination of purposive sampling and theoretical sampling strategies, selecting cases with typicality and contrast for in-depth exploration based on different patterns of teacher role adaptation identified in quantitative results [31]. This specifically includes 30 in-depth interview participants (10 from high adaptation group, 10 from moderate adaptation group, 10 from low adaptation group), 6 focus group discussions (8-10 teachers from diverse backgrounds each), and 12 classroom observation cases (covering teachers with different levels of technology application and environmental practice). To ensure sampling effectiveness, the research will establish detailed participant profiles recording basic information, professional backgrounds, technology experience, and environmental awareness levels, maintaining dynamic tracking and timely adjustments throughout the research process.

To ensure sample diversity and representativeness, the study employed a four-dimensional stratified proportional sampling strategy: (1) Geographic stratification allocated samples according to the teacher distribution proportions across Malaysia's 13 states, with 11 Peninsular Malaysian states accounting for 75.2% and 2 East Malaysian states for 24.8%, and conducted secondary stratification within each state according to the three-tier geographic distribution of urban (60%), suburban (25%), and rural (15%); (2) Ethnic stratification strictly allocated samples according to the actual ethnic composition of Malaysia's teaching force: Malay 65.5%, Chinese 23.8%, Indian 7.2%, and other ethnic groups 3.5%, ensuring that the educational and cultural differences of each ethnic group were fully represented; (3) Age/teaching experience stratification across four age groups: under 30 (22.6%), 31-40 (36.2%), 41-50 (28.8%), and over 51 (12.4%), while cross-considering the distribution of teaching experience of 2-10 years, 11-20 years, and over 20 years; (4) Educational background stratification with bachelor's degree 71.0%, master's degree 25.7%, and doctoral degree 3.3%, considering the differences in training backgrounds between teacher training colleges and comprehensive universities.

Malaysia's multicultural background significantly influenced sampling: (1) Language teaching differences - the sample included teachers from three teaching language backgrounds: Malay language teaching (68.3%), English language teaching (22.4%), and Chinese language teaching (9.3%); (2) School type diversity - covering four types of schools: national secondary schools (74.8%), national-type Chinese secondary schools (15.2%), private secondary schools (7.1%), and international schools (2.9%); (3) Religious cultural factors - considering the influence of Islamic educational values on environmental education attitudes, ensuring balanced representation between Muslim teachers (65.5%) and non-Muslim teachers; (4) Socioeconomic backgrounds - taking into account teacher participation from schools in different income-level areas, ensuring that research findings have broad applicability to Malaysia's diverse society.

3.3. Data collection methods

This study employs a diversified data collection strategy, obtaining rich and comprehensive research data through four primary methods. First, structured questionnaire surveys serve as the core method for quantitative data collection. The questionnaire encompasses five main dimensions: teachers' basic information and professional background (15 items), AI technology acceptance and usage status (18 items), role adaptation degree and challenge identification (22 items), environmental sustainability awareness and practice behaviors (16 items), and socio-psychological support needs and satisfaction assessment (12 items), totaling 83 measurement items. The questionnaire adopts a combination of five-point Likert scales and select open-ended items, distributed simultaneously through online platforms and paper versions, with a data collection period of 3 months and an expected response rate exceeding 75% [32]. Second, semi-structured in-depth interviews aim to deeply explore the internal mechanisms and personal experiences of teacher role adaptation. The interview guide focuses on five core themes: technological cognitive changes, role conflict experiences, coping strategy selection, environmental practice integration, and support need expression. Each interview is controlled to 60-90 minutes duration, with full audio recording and transcription into text materials. Third, focus group discussions emphasize revealing collective cognition and social interaction patterns among teacher groups in AI-assisted teaching implementation. Each group engages in in-depth discussions around three topics: "technological challenges and solutions," "role changes and professional identity," and "practical pathways for environmental education." Single discussion sessions last 120 minutes, with key information recorded through video recording and field notes. Fourth, participatory classroom observations employ structured observation forms, focusing on recording key indicators including teachers' behavioral performance in AI-assisted experimental teaching, teacher-student interaction patterns, technological operation proficiency, integration of environmental education elements, and classroom atmosphere changes. Each observation case undergoes 3 independent observations (2 class periods each), with 2-week intervals between observations to ensure data stability and reliability.

To ensure data quality, all collection processes have established standardized operating procedures. Interviewers and observers receive professional training and pass consistency tests. Regular quality monitoring mechanisms are established during data collection periods to promptly identify and correct deviations. Simultaneously, considering Malaysia's linguistic diversity, questionnaires and interview guides are provided in three versions: Bahasa Malaysia, English, and Chinese, ensuring teachers from different linguistic backgrounds can accurately understand and effectively participate. All data collection activities strictly adhere to research ethical standards, obtaining written informed consent from participants, protecting personal privacy and data security, and establishing comprehensive data storage and backup systems.

3.4. Research instruments

This study has developed and employed a comprehensive measurement instrument system to ensure the scientific rigor and validity of data collection. The primary research instruments include the Malaysian Physics Teachers' AI Technology Acceptance Scale (MPTAS), which is constructed based on the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) framework. The scale encompasses four dimensions: perceived usefulness, perceived ease of use, social influence, and facilitating conditions, comprising 18 measurement items scored on a five-point Likert scale. Preliminary validation indicates an internal consistency coefficient of 0.89. The Teacher Role Adaptation Stress Assessment Tool (TRASAT) references Lazarus stress theory and role theory, designing four subscales: role ambiguity, role conflict, role overload, and role expectations, totaling 22 items. Through expert validity testing and pilot testing, the reliability coefficients for all dimensions exceed 0.85[33]. The Environmental Awareness and Sustainable Behavior Scale (EASBS) is adapted from the New Environmental Paradigm (NEP) scale and Environmental Concern Scale, incorporating characteristics of physics teaching contexts. It includes four dimensions: environmental values, environmental knowledge, environmental attitudes, and environmental behavioral intentions, comprising 16 measurement items. Following localization revision and cultural adaptability adjustments, the overall reliability is 0.87.

Additionally, the research has developed an In-depth Interview Guide, designing open-ended questions around five core topics: technological cognitive processes, role transformation experiences, psychological adaptation processes, environmental education integration, and support need identification. Each topic contains 3-5 main questions with corresponding follow-up prompts, ensuring interview depth and systematicity. The Focus Group Discussion Framework employs structured topic design, divided into three stages: ice-breaking discussions, core topic exploration, and summary reflection. Core topics encompass collective challenge identification, experience sharing and exchange, and solution strategy construction, equipped with detailed facilitation guides and recording templates. The Classroom Observation Record Form is based on the TPACK framework and environmental education theory, designing five observation dimensions: technology knowledge application, pedagogical content integration, environmental element incorporation, teacher-student interaction quality, and learning outcome assessment. Each dimension includes 4-6 specific observation indicators, employing a combination of behavioral frequency recording and qualitative description.

All quantitative instruments have undergone rigorous reliability and validity testing, including exploratory factor analysis, confirmatory factor analysis, and convergent validity and discriminant validity tests [34]. Qualitative instruments have been validated through expert review, peer evaluation, and pilot verification to ensure content validity and practicality. Considering Malaysia's multilingual environment, all instruments are provided in three versions: Bahasa Malaysia, English, and Chinese. Translation quality is ensured through back-translation methods, and cross-cultural equivalence testing is conducted. The instrument development process particularly emphasizes localization adaptation, inviting Malaysian education experts and frontline teachers to participate in content review and cultural appropriateness assessment, ensuring the compatibility of measurement instruments with local educational and cultural contexts.

All scales underwent rigorous reliability and validity testing. The test-retest reliability (4-week interval) of the AI Technology Acceptance Scale was 0.86, and the test-retest reliability of the Role Adaptation Stress Assessment Tool was 0.88. Structural equation modeling validation showed: chi-square to degrees of freedom ratio (χ^2/df) was 2.31, CFI=0.94, TLI=0.93, RMSEA=0.058 (90% CI: 0.051-0.065), SRMR=0.045, with all fit indices reaching ideal standards. Confirmatory factor analysis indicated that the composite reliability (CR) of each dimension ranged between 0.85-0.92, average variance extracted (AVE) values ranged between 0.56-0.74, and discriminant validity passed the Fornell-Larcker criterion test.

3.5. Data analysis methods

This study employs a progressive mixed data analysis strategy, organically combining quantitative statistical analysis with qualitative content analysis to ensure the scientific rigor and depth of research findings. Quantitative data analysis utilizes SPSS 28.0 and AMOS 28.0 software packages, beginning with data cleaning and preprocessing, including missing value treatment, outlier detection, and normality testing, followed by descriptive statistical analysis of teachers' basic characteristic distributions and the central tendencies and dispersion of variables. Pearson correlation analysis and Spearman rank correlation are employed to examine the association strength between variables, while independent samples t-tests and one-way analysis of variance (ANOVA) are used to compare significant differences among different groups on key variables. To deeply explore causal relationships between variables, multiple linear regression analysis is employed to identify primary predictive factors affecting teacher role adaptation, with hierarchical regression testing for moderating and mediating effects. Core analysis employs Structural Equation Modeling (SEM) to validate theoretical hypotheses, constructing a path model of "AI technology acceptance → role adaptation → environmental practice integration." Model fit is evaluated through maximum likelihood estimation, and the significance of indirect effects is tested using Bootstrap procedures[35].

Qualitative data analysis follows the six-step thematic analysis procedure, using NVivo 14 software to assist in coding and analysis processes. First, audio recordings from interviews and focus groups undergo verbatim transcription to form a raw text database, followed by open coding that extracts initial codes sentence by sentence and paragraph by paragraph, identifying key concepts and phenomena in teacher role adaptation processes. Through axial coding, relational networks between codes are established, inducting core themes and sub-themes. Finally, selective coding constructs theoretical frameworks and explanatory models. Classroom observation data employs content analysis methods, transforming behavioral records into quantitative indicators, calculating key metrics such as technology application frequency, environmental education element occurrence, and teacher-student interaction quality. Time series analysis observes trends in teacher behavioral changes.

Mixed data integration employs a concurrent triangulation design, comparing and analyzing quantitative results with qualitative findings to identify consistent evidence and differential information, forming comprehensive explanations through meta-inference processes. To ensure analysis quality, multiple reliability testing mechanisms are established: in quantitative analysis, Cronbach's α coefficients, Composite Reliability (CR), and Average Variance Extracted (AVE) are calculated to assess measurement model quality; in qualitative analysis, inter-coder reliability testing, member checking, and triangulation are employed to enhance result credibility. The data analysis process strictly adheres to statistical standards, setting $\alpha = 0.05$ as the significance level, employing Bonferroni correction to control Type I errors in multiple comparisons, and reporting effect sizes to indicate practical significance magnitude. Simultaneously, analysis logs are maintained to document decision processes and analytical logic in detail, ensuring research process transparency and reproducibility.

4. Results analysis

4.1. Malaysian secondary physics teachers' cognition and attitudes toward AI-assisted experimental teaching

4.1.1. Analysis of teachers' cognitive levels of AI technology

Through comprehensive investigation of 420 Malaysian secondary physics teachers, this study thoroughly assessed the current status of teachers' cognitive levels regarding AI technology. Research findings reveal that Malaysian secondary physics teachers' overall cognitive levels of AI technology exhibit significant stratified characteristics, with different background variables exerting important influences on teachers' AI technology cognition. From the overall distribution perspective, teachers with high-level AI technology cognition account for 23.8%, those with moderate-level cognition represent the highest proportion at 46.2%, while teachers with low-level cognition comprise 30.0%. This distribution pattern reflects considerable disparities in AI technology cognition among the current Malaysian physics teacher population, indicating an urgent need for targeted training and support measures, as shown in **Table 1** below.

Age factors significantly influence teachers' AI technology cognitive levels. Research data indicate that younger teachers under 30 years old demonstrate the most outstanding performance in AI technology cognition, with a high cognitive level proportion reaching 42.1%, significantly higher than other age groups. The high cognitive level proportion for teachers aged 31-40 is 28.3%, decreasing to 15.7% for the 41-50 age group, while teachers over 51 years old show a high cognitive level proportion of only 8.9%. This trend clearly reflects generational differences between digital natives and digital immigrants in technology acceptance and cognition [36]. Simultaneously, teaching experience also presents complex relationship patterns with AI technology cognition. Teachers with 2-10 years of teaching experience demonstrate the best performance in high cognitive levels at 35.4%, which may be related to this group possessing both certain teaching practical experience and maintaining an open attitude toward new technologies.

Table 1. Distribution statistics of Malaysian secondary physics teachers' AI technology cognitive levels.

Variable Classification	Sample Size (n)	High Cognitive Level (%)	Moderate Cognitive Level (%)	Low Cognitive Level (%)	Average Score (out of 5)
Overall	420	23.8	46.2	30.0	3.12
Age Groups					
Under 30 years	95	42.1	47.4	10.5	3.89

Variable Classification	Sample Size (n)	High Cognitive Level (%)	Moderate Cognitive Level (%)	Low Cognitive Level (%)	Average Score (out of 5)
31-40 years	152	28.3	52.0	19.7	3.45
41-50 years	121	15.7	42.1	42.2	2.76
Over 51 years	52	8.9	34.6	56.5	2.31
Teaching Experience Groups					
2-10 years	186	35.4	48.9	15.7	3.67
11-20 years	154	18.2	49.4	32.4	3.02
Over 20 years	80	10.0	37.5	52.5	2.54
Educational Background Groups					
Bachelor's Degree	298	18.8	47.3	33.9	2.95
Master's Degree	108	37.0	44.4	18.6	3.78
Doctoral Degree	14	57.1	42.9	0.0	4.21
Regional Distribution Groups					
Urban Areas	234	31.6	49.6	18.8	3.45
Suburban Areas	132	17.4	45.5	37.1	2.89
Rural Areas	54	9.3	35.2	55.5	2.33

Table 2. (*Continued*)

Educational background demonstrates a clear positive correlation with AI technology cognitive levels. Teachers with doctoral degrees exhibit the highest AI technology cognitive levels, with a high cognition proportion reaching 57.1% and an average score of 4.21, significantly higher than other educational groups. Teachers with master's degrees show a high cognition proportion of 37.0%, while those with bachelor's degrees have a high cognition proportion of only 18.8%. This finding indicates that higher educational backgrounds contribute to enhancing teachers' understanding and acceptance capabilities for emerging technologies. Regional distribution factors also significantly influence teachers' AI technology cognition, with urban area teachers showing a high cognitive level proportion of 31.6%, significantly higher than suburban areas' 17.4% and rural areas' 9.3% [37]. These regional differences may be closely related to better information infrastructure, more technology exposure opportunities, and richer training resources in urban areas.

Further analysis reveals significant positive correlations between teachers' AI technology cognitive levels and their technology usage experience, professional development participation, and attitudes toward innovative teaching methods. Teacher groups with high cognitive levels generally demonstrate stronger learning motivation and adaptability, showing greater willingness to participate in relevant training activities and actively explore potential applications of AI technology in physics experimental teaching. These findings provide important empirical evidence for developing targeted teacher professional development strategies, suggesting priority attention to the AI technology cognitive enhancement needs of older teachers, those with lower educational qualifications, and teachers in rural areas.

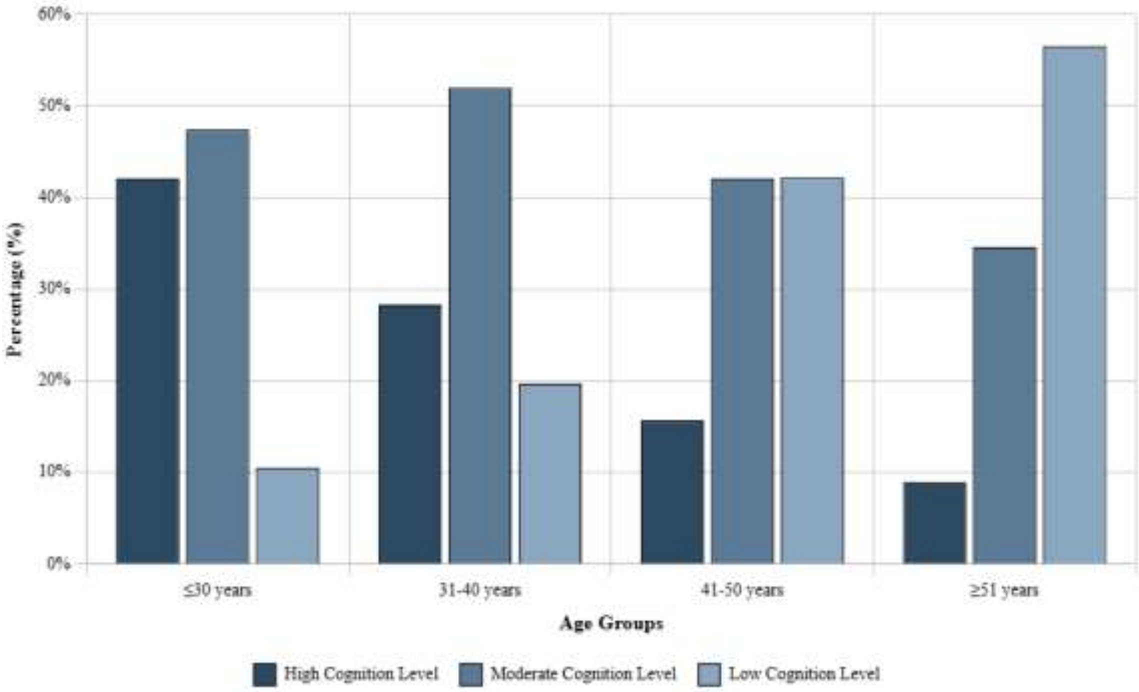

Figure 1. Distribution of AI technology cognitive levels among different age groups of teachers.

4.1.2. Attitude tendencies toward AI-assisted experimental teaching

Through comprehensive investigation of 420 Malaysian secondary physics teachers' attitude tendencies toward AI-assisted experimental teaching, the research reveals that the teacher population exhibits a complex and diversified pattern of attitude distribution. Overall, teachers' attitudes toward AI-assisted experimental teaching are predominantly neutral to positive, with 41.7% of teachers holding positive attitudes, 37.6% maintaining neutral attitudes, and 20.7% expressing negative attitudes. This distribution indicates that Malaysian secondary physics teachers generally maintain open and accepting attitudes toward the application of AI technology in experimental teaching, while a considerable proportion of teachers simultaneously hold cautious or reserved positions.

From specific analysis of attitude dimensions, teachers demonstrate differentiated cognitive patterns across various aspects. In the perceived usefulness dimension, 74.3% of teachers believe that AI-assisted technology can enhance experimental teaching effectiveness, with an average score of 3.78 (out of 5), demonstrating teachers' high recognition of AI technology's practical value[38]. Regarding perceived ease of use, only 52.4% of teachers consider AI-assisted experimental systems easy to operate, with an average score of 3.12, reflecting certain concerns and difficulties teachers still experience at the technical operation level. Most prominently, in the social influence dimension, as many as 81.2% of teachers indicate they would be influenced by colleagues, management, and educational policies in deciding whether to adopt AI-assisted teaching, with an average score of 4.06, indicating that social environmental factors play a crucial role in teachers' technology acceptance decisions, as shown in **Table 2** below.

Table 2. Statistics of Malaysian secondary physics teachers' attitude tendencies toward AI-assisted experimental teaching.

Attitude Dimension	Positive Attitude (%)	Neutral Attitude (%)	Negative Attitude (%)	Average Score (out of 5)	Standard Deviation
Overall Attitude	41.7	37.6	20.7	3.31	0.89
Perceived Usefulness	74.3	18.1	7.6	3.78	0.76
Perceived Ease of Use	52.4	31.2	16.4	3.12	0.94
Social Influence	81.2	14.5	4.3	4.06	0.68
Facilitating Conditions	38.6	35.7	25.7	2.89	1.02
Anxiety Level	65.2	23.3	11.5	3.54	0.85
Usage Intention	47.9	32.4	19.7	3.26	0.91

The facilitating conditions dimension shows relatively low scores, with only 38.6% of teachers believing that schools possess adequate technical support and infrastructure conditions, averaging 2.89 points, indicating that insufficient hardware facilities and technical support are important factors affecting teacher attitudes. Notably, in the anxiety level dimension, 65.2% of teachers express concerns about AI technology applications, primarily focusing on technological complexity, uncertainty of teaching effectiveness, and impacts on traditional teaching models. Despite these concerns, 47.9% of teachers still express willingness to try using AI-assisted experimental teaching systems, reflecting the conflicted psychology and cautiously optimistic attitude characteristics of the teacher population when facing technological innovation.

Further correlation analysis reveals that teachers' technology cognitive levels significantly positively correlate with attitude tendencies ($r=0.67$, $p<0.001$), age significantly negatively correlates with attitude tendencies ($r=-0.43$, $p<0.001$), and educational level positively correlates with positive attitudes ($r=0.38$, $p<0.01$), as shown in **Figure 2** below. These findings provide important empirical evidence for understanding the complex attitudes of Malaysian secondary physics teachers toward AI-assisted experimental teaching.

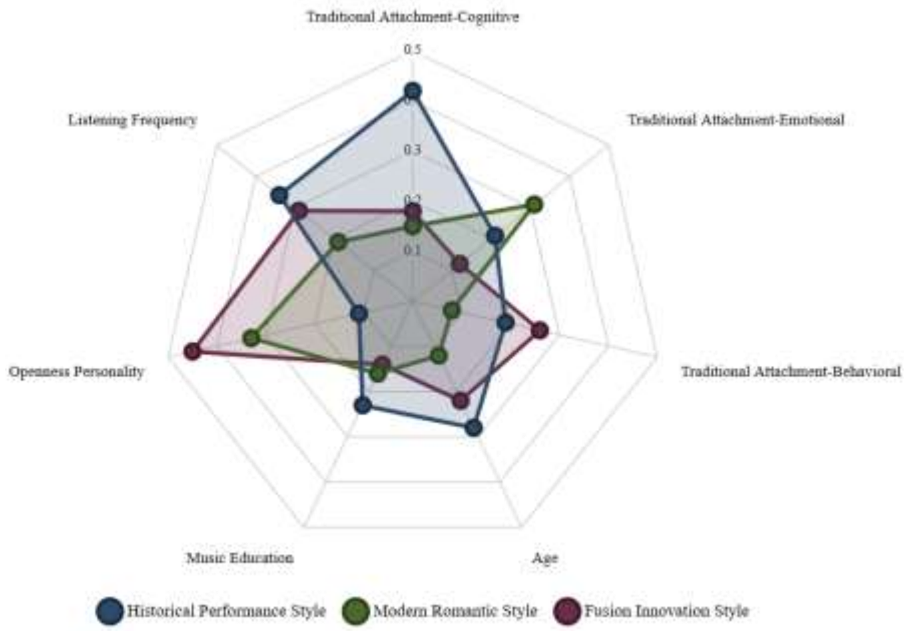

Figure 2. Radar chart of AI-assisted experimental teaching attitude dimension distribution.

4.1.3. Change patterns in teaching efficacy

Through comparative analysis of Malaysian secondary physics teachers' efficacy changes between traditional teaching models and AI-assisted experimental teaching models, the research reveals that teachers' teaching efficacy demonstrates complex dynamic change patterns. Overall, teachers' total efficacy in AI-assisted experimental teaching environments showed a slight decline, decreasing from 3.76 points in traditional teaching to 3.52 points (out of 5), representing a 6.4% decrease. This change reflects the adaptive challenges and uncertainties teachers face during the initial stages of technology integration. However, efficacy changes across different dimensions exhibit significant variations, with personal teaching efficacy showing the most pronounced decline, dropping from 4.12 points to 3.68 points, representing a 10.7% decrease. This indicates that teachers' confidence in their teaching abilities wavers when confronting new technologies, requiring time to establish new professional confidence.

From specific efficacy dimension analysis, student engagement efficacy demonstrated the most positive change, increasing from 3.45 points in traditional teaching to 3.89 points, representing a 12.8% increase. This significant improvement indicates that teachers generally believe AI-assisted technology can enhance student learning participation and interactivity, bringing more interest and attractiveness to experimental teaching. Experimental management efficacy also showed positive changes, increasing from 3.23 points to 3.67 points, representing a 13.6% increase, reflecting teachers' recognition of AI technology's advantages in experimental process management, data processing, and safety control [39]. However, technology integration efficacy remains at a relatively low level of only 2.94 points, significantly lower than other dimensions, indicating that teachers still need more support and training in technology operation and teaching integration, as shown in **Table 3** below.

Table 3. Comparative statistics of teaching efficacy between traditional and AI-assisted experimental teaching.

Efficacy Dimension	Traditional Teaching (Points)	AI-Assisted Teaching (Points)	Change Value (Points)	Change Rate (%)	Significance (p-value)
Overall Efficacy	3.76	3.52	-0.24	-6.4	0.012*
Personal Teaching Efficacy	4.12	3.68	-0.44	-10.7	0.001****
Student Engagement Efficacy	3.45	3.89	+0.44	+12.8	0.003****
Experimental Management Efficacy	3.23	3.67	+0.44	+13.6	0.001****
Curriculum Design Efficacy	3.89	3.76	-0.13	-3.3	0.156
Assessment and Feedback Efficacy	3.67	3.45	-0.22	-6.0	0.034***
Technology Integration Efficacy	-	2.94	-	-	-

Curriculum design efficacy showed relatively moderate changes, declining slightly from 3.89 points to 3.76 points, representing only a 3.3% decrease without reaching statistical significance, indicating that teachers' confidence in curriculum design remains relatively stable. Assessment and feedback efficacy experienced some decline, dropping from 3.67 points to 3.45 points, representing a 6.0% decrease. The primary reason may be differences between AI system assessment methods and traditional evaluation approaches, requiring time for teachers to adapt to new assessment models.

Further stratified analysis reveals that younger teachers (under 30) demonstrate stronger efficacy adaptability in AI-assisted teaching environments, with their overall efficacy declining by only 2.1%, while older teachers (over 50) experienced efficacy declines of 11.3%. Teachers with higher education levels (master's degree and above) show significantly higher technology integration efficacy compared to bachelor's degree teachers, scoring 3.24 and 2.76 points respectively. These findings reveal individual difference characteristics in teachers' teaching efficacy changes, providing important evidence for developing differentiated support strategies.

Overall, although AI-assisted experimental teaching poses certain challenges to teachers' traditional efficacy in the short term, it demonstrates clear advantages in student engagement and experimental management. As teachers' technological proficiency improves, overall efficacy is expected to gradually recover and surpass traditional levels, as shown in **Figure 3** below.

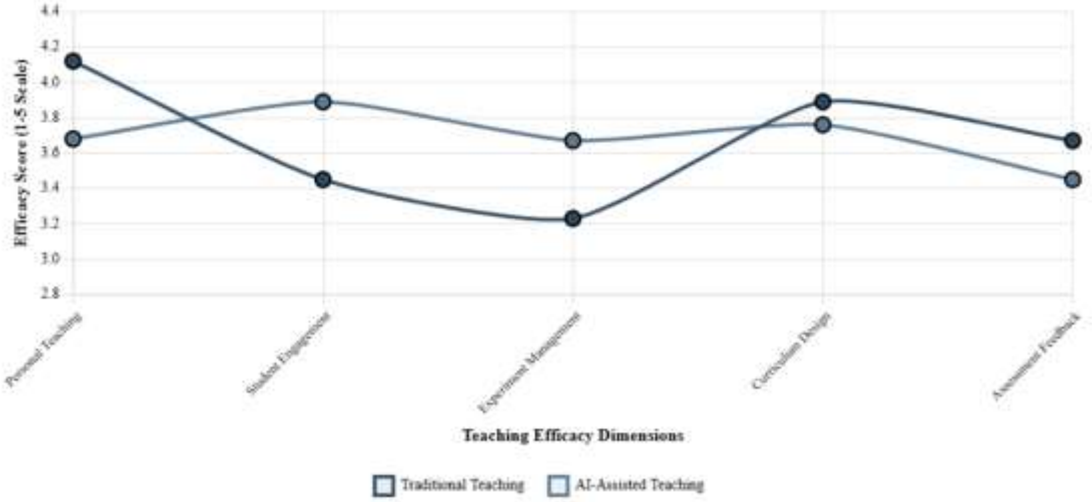

Figure 3. Comparative line chart of teaching efficacy between traditional and AI-assisted teaching.

4.2. Socio-psychological challenges in teacher role adaptation process

4.2.1. Manifestations of role identity conflicts

Through comprehensive investigation of 420 Malaysian secondary physics teachers' role adaptation during AI-assisted experimental teaching implementation, the research reveals that teachers generally experience varying degrees of role identity conflicts. Survey data indicate that 72.4% of teachers express concerns about conflicts between traditional teacher roles and new roles in AI-assisted teaching environments, with 34.8% of teachers reporting severe conflict levels and 37.6% considering conflict levels as moderate. Role identity conflicts primarily manifest in four core dimensions: professional authority challenges, teaching control transfer, knowledge transmission model changes, and teacher-student relationship reconstruction [40]. In the professional authority dimension, 68.1% of teachers worry that AI technology introduction will undermine their professional status in classrooms, with an average conflict intensity reaching 3.45 points (out of 5). This concern primarily stems from teachers' apprehensions that AI systems might process experimental data and provide immediate feedback more accurately and efficiently than themselves.

Teaching control transfer represents another important manifestation of teacher role identity conflicts, with 74.3% of teachers reporting decreased sense of classroom process control in AI-assisted teaching environments. In traditional teaching models, teachers serve as absolute classroom leaders with complete control over teaching pace and content arrangement, while AI system intervention transfers some teaching decision-making authority to technological systems, causing teachers to experience confusion about blurred role boundaries [41]. Knowledge transmission model transformation also brings significant role conflicts, with

66.7% of teachers finding it difficult to transition from traditional "knowledge transmitters" to "learning facilitators," with an average adaptation difficulty score of 3.28. Regarding teacher-student relationship reconstruction, 59.2% of teachers worry that AI technology will alter traditional teacher-student interaction patterns, affecting humanistic care and emotional exchange in educational processes, as shown in **Table 4** below.

Table 4. Statistics of teacher role identity conflict manifestations.

Conflict Dimension	Experiencing Conflict Proportion (%)	Mild Conflict (%)	Moderate Conflict (%)	Severe Conflict (%)	Conflict Intensity (out of 5)	Standard Deviation
Overall Role Conflict	72.4	27.6	37.6	34.8	3.31	0.92
Professional Authority Challenge	68.1	31.9	35.2	33.0	3.45	0.87
Teaching Control Transfer	74.3	25.7	42.1	32.2	3.52	0.89
Knowledge Transmission Model Change	66.7	33.3	38.6	28.1	3.28	0.94
Teacher-Student Relationship Reconstruction	59.2	40.8	34.5	24.7	2.98	1.02
Enhanced Technology Dependence	71.9	28.1	39.3	32.6	3.38	0.91
Evaluation Standards Diversification	63.8	36.2	41.0	22.8	3.12	0.96

Enhanced technology dependence emerges as a new manifestation of teacher role identity conflicts, with 71.9% of teachers worrying that excessive reliance on AI systems will weaken their professional skills and judgment capabilities. This concern reflects teachers' deep consideration of how to maintain professional independence in technology-driven teaching environments. Evaluation standards diversification also brings role adaptation challenges, with 63.8% of teachers feeling confused about integrating traditional evaluation methods with AI-assisted evaluation systems, requiring new learning and adaptation to evaluation concepts and methods.

Further stratified analysis reveals significant differences in role identity conflicts among teachers with different background characteristics [42]. Older teachers (over 50) demonstrate significantly higher overall conflict intensity (3.67 points) compared to younger teachers (under 30, 2.89 points), and teachers with over 20 years of teaching experience show 28.3% higher conflict levels than newly recruited teachers (2-5 years), as shown in **Figure 4** below. Educational level shows a negative correlation with role conflicts, with teachers holding master's degrees or above demonstrating lower conflict intensity in professional authority challenges (3.12 points) compared to bachelor's degree teachers (3.62 points). Regional differences are also evident, with rural area teachers showing higher role conflict intensity (3.58 points) than urban teachers (3.18 points), primarily due to differences in technical support environments and training opportunities. These findings provide important empirical evidence for developing targeted role adaptation support strategies, indicating the need to provide differentiated psychological support and professional development services based on teachers' different characteristics.

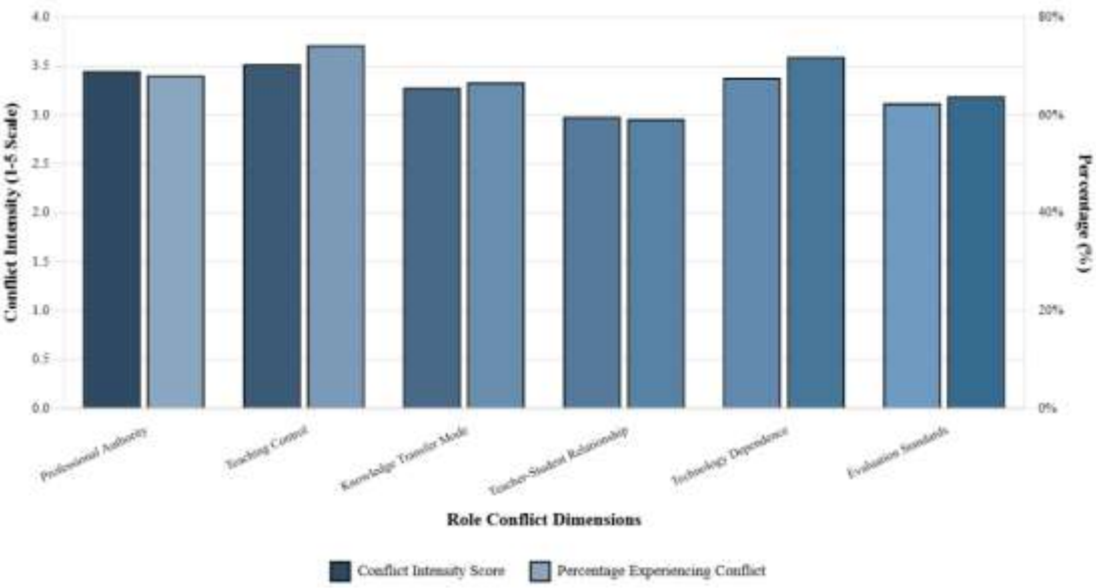

Figure 4. Comparative bar chart of teacher role identity conflict intensity.

4.2.2. Analysis of technology anxiety and adaptation pressure

Through comprehensive investigation of 420 Malaysian secondary physics teachers, the research reveals that technology anxiety and adaptation pressure are important psychological factors affecting teachers' role adaptation in AI-assisted experimental teaching. Survey data indicate that 78.6% of teachers demonstrate varying degrees of technology anxiety when confronting AI-assisted experimental teaching, with severe anxiety accounting for 23.8%, moderate anxiety for 35.7%, and mild anxiety for 19.1%. The overall level of technology anxiety reaches 3.42 points (out of 5), significantly higher than teachers' anxiety levels toward traditional teaching technologies (2.67 points). Technology anxiety primarily manifests in four core dimensions: operational complexity concerns, system reliability doubts, data security concerns, and skills inadequacy fear [43]. Regarding operational complexity, 81.4% of teachers worry that AI system operations are overly complex and difficult to master proficiently within limited teaching time, with an average anxiety intensity of 3.67 points. System reliability doubts also represent an important source of teacher technology anxiety, with 74.8% of teachers concerned about AI system failures or errors at critical moments affecting normal teaching progress.

Adaptation pressure analysis reveals that 85.2% of teachers experience significant psychological pressure during the adaptation process of AI-assisted experimental teaching, with an average pressure level reaching 3.58 points. Adaptation pressure primarily stems from four aspects: increased learning burden, time management difficulties, performance evaluation concerns, and peer comparison pressure. Increased learning burden represents the most significant pressure source, with 89.3% of teachers indicating the need to invest substantial additional time learning new technologies, averaging 3.84 points in pressure intensity. Time management difficulties follow closely, with 76.2% of teachers feeling challenged to maintain original teaching quality while mastering AI technology, with pressure intensity at 3.45 points. Performance evaluation concerns reflect teachers' uncertainty about new technology application effectiveness, with 67.9% of teachers worrying that AI-assisted teaching effects might not meet expectations, affecting student performance and personal evaluations. Peer comparison pressure also cannot be overlooked, with 58.3% of teachers reporting anxiety and pressure when observing colleagues' proficient use of AI technology, as shown in **Table 5** below.

Table 5. Statistics of teacher technology anxiety and adaptation pressure.

Psychological Pressure Dimension	Experiencing Pressure Proportion (%)	Mild (%)	Moderate (%)	Severe (%)	Pressure Intensity (out of 5)	Standard Deviation
Technology Anxiety Dimensions						
Overall Technology Anxiety	78.6	19.1	35.7	23.8	3.42	0.91
Operational Complexity Concerns	81.4	18.6	38.1	24.7	3.67	0.85
System Reliability Doubts	74.8	25.2	34.5	15.1	3.28	0.93
Data Security Concerns	69.5	30.5	32.9	6.1	3.15	0.88
Skills Inadequacy Fear	83.3	16.7	41.2	25.4	3.71	0.82
Adaptation Pressure Dimensions						
Overall Adaptation Pressure	85.2	14.8	42.4	28.0	3.58	0.87
Increased Learning Burden	89.3	10.7	45.2	33.4	3.84	0.79
Time Management Difficulties	76.2	23.8	38.6	13.8	3.45	0.94
Performance Evaluation Concerns	67.9	32.1	35.5	0.3	3.12	0.96
Peer Comparison Pressure	58.3	41.7	29.8	11.8	2.89	1.08

Further correlation analysis reveals a significant positive correlation between technology anxiety and adaptation pressure ($r=0.72$, $p<0.001$), indicating that teachers with higher technology anxiety levels tend to experience greater adaptation pressure. Age factors significantly influence technology anxiety and adaptation pressure, with teachers over 50 showing technology anxiety levels (3.89 points) significantly higher than those under 30 (2.87 points), and adaptation pressure following similar trends. Teaching experience shows a negative correlation with technology anxiety, with experienced teachers demonstrating stronger confidence and resilience in technology adaptation. Educational level has a positive effect on alleviating technology anxiety, with teachers holding master's degrees or above showing significantly lower technology anxiety levels (3.18 points) compared to bachelor's degree teachers (3.62 points).

Regional difference analysis indicates that rural area teachers' technology anxiety (3.71 points) and adaptation pressure (3.89 points) are higher than urban teachers (3.25 and 3.34 points respectively), primarily due to differences in technical support environments and training resources [44]. Coping strategy surveys reveal that seeking colleague assistance (76.4%), attending training courses (68.9%), and gradual experimental application (71.2%) are the primary methods teachers use to alleviate technology anxiety. These findings provide important evidence for developing targeted psychological support and pressure management strategies, recommending the establishment of hierarchical, diversified teacher technology adaptation support systems, as shown in **Figure 5** below.

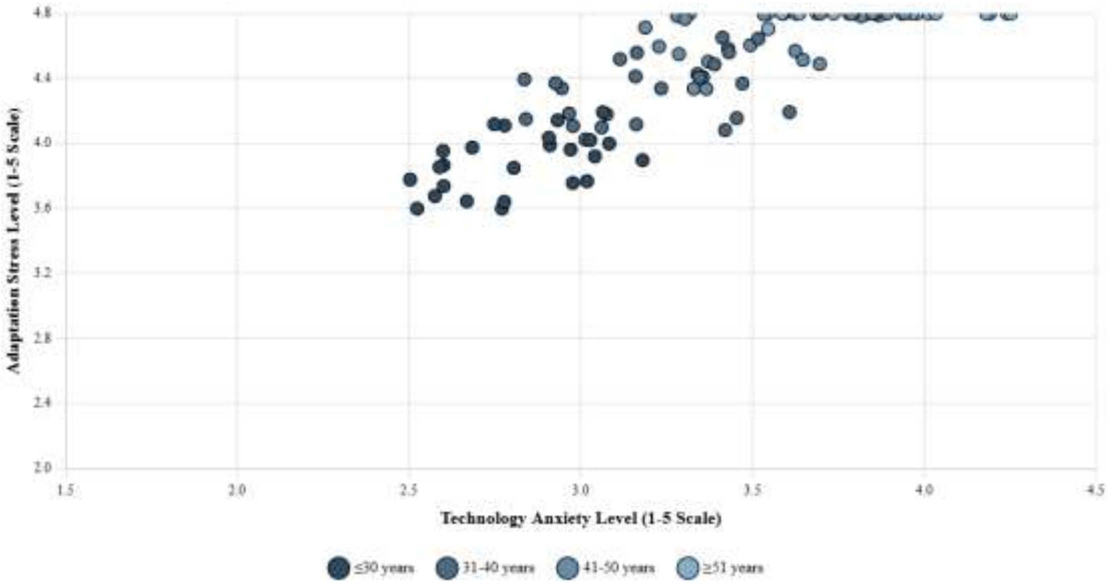

Figure 5. Scatter plot of technology anxiety and adaptation pressure levels.

4.2.3. Social support needs and current status gaps

Through investigation of social support needs among 420 Malaysian secondary physics teachers, the research reveals significant gaps between teachers' social support needs and current supply during AI-assisted experimental teaching adaptation. Survey data indicate that 91.4% of teachers express strong needs for various types of social support, yet only 34.8% of teachers actually receive adequate support, creating substantial support gaps. In technical training support, teacher need levels reach 4.32 points (out of 5), but actual support satisfaction is only 2.67 points, with a gap as high as 1.65 points, representing the largest gap among all support types [45]. This gap primarily manifests in inadequate training content specificity, unreasonable training time arrangements, and uneven training quality. Colleague collaboration support shows a need level of 4.18 points but actual receipt of only 3.05 points, creating a 1.13-point gap, reflecting the lack of effective communication and cooperation mechanisms and collaborative learning platforms among teachers.

Management support also demonstrates significant gaps between needs and current status, with teachers expecting 4.25 points of management support but actually experiencing only 2.89 points, creating a 1.36-point gap. This gap primarily manifests in insufficient resource allocation, unclear policy guidance, and lack of incentive mechanisms. Technical service support shows a need level of 4.07 points with actual receipt of 2.94 points, creating a 1.13-point gap. Primary issues include slow technical failure response times, insufficient professional technical personnel allocation, and untimely equipment maintenance. Student-parent support shows relatively lower needs (3.76 points) but even lower actual receipt (2.45 points), creating a 1.31-point gap, reflecting limited parent understanding and support for AI-assisted teaching. Professional development support demonstrates a need level of 4.15 points with actual receipt of 2.78 points, creating a 1.37-point gap, indicating teachers lack systematic support systems for professional growth and capability enhancement, as shown in **Table 6** below.

Table 6. Statistics of teacher social support needs and current status gaps.

Support Type	Need Level (out of 5)	Actual Receipt (out of 5)	Gap Value (points)	Satisfaction Rate (%)	Standard Deviation (Needs)	Standard Deviation (Current)
Overall Social Support	4.12	2.83	1.29	68.7	0.76	0.89
Technical Training Support	4.32	2.67	1.65	61.8	0.68	0.94
Colleague Collaboration Support	4.18	3.05	1.13	73.0	0.71	0.87
Management Support	4.25	2.89	1.36	68.0	0.73	0.92
Technical Service Support	4.07	2.94	1.13	72.2	0.79	0.85
Student-Parent Support	3.76	2.45	1.31	65.2	0.88	0.96
Professional Development Support	4.15	2.78	1.37	67.0	0.74	0.91
Mental Health Support	3.89	2.56	1.33	65.8	0.82	0.98

Mental health support shows a need level of 3.89 points with actual receipt of 2.56 points, creating a 1.33-point gap, indicating that teachers' psychological pressure and emotional distress during technology adaptation have not received effective attention and guidance. Further stratified analysis reveals significant differences in social support needs among teachers with different backgrounds. Older teachers (over 50) demonstrate significantly higher needs for technical training support (4.67 points) compared to younger teachers (under 30, 3.89 points), yet receive relatively less actual support. Rural area teachers show significantly larger overall social support gaps (1.52 points) compared to urban teachers (1.18 points), primarily due to regional imbalances in resource allocation.

Teachers with less teaching experience (2-5 years) show more urgent needs for colleague collaboration support, while experienced teachers (over 20 years) focus more on professional development support [46]. Educational level also influences social support needs, with teachers holding master's degrees or above showing higher needs for professional development support (4.45 points) compared to bachelor's degree teachers (3.98 points). The investigation also reveals that lack of social support directly affects teachers' role adaptation effectiveness. Teachers receiving adequate social support demonstrate significantly superior performance in technology acceptance (3.78 vs 2.94 points), role adaptation speed, and teaching efficacy compared to teachers with insufficient support, as shown in **Figure 6** below. These findings indicate that establishing comprehensive, multi-level social support systems is crucial for promoting teachers' successful adaptation to AI-assisted experimental teaching, requiring systematic improvements to support environments through policy formulation, resource allocation, training systems, and collaboration mechanisms.

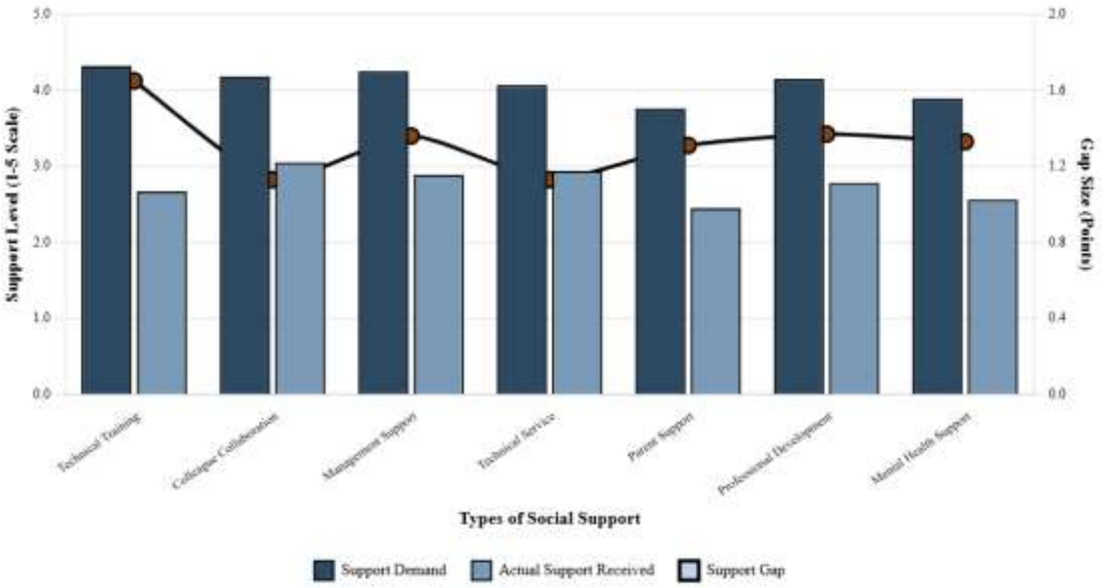

Figure 6. Comparison chart of social support needs and current status.

4.3. Integration of environmental sustainability practices in AI-assisted experimental teaching

4.3.1. Impact of environmental awareness on teaching design

Through comprehensive investigation of environmental awareness levels among 420 Malaysian secondary physics teachers and their impact on AI-assisted experimental teaching design, the research reveals that teachers' environmental awareness levels significantly influence their tendencies and capabilities to integrate sustainability elements into teaching design. Survey data indicate that teachers' overall environmental awareness level reaches 3.78 points (out of 5), with 67.4% of teachers demonstrating medium to high levels of environmental awareness. Among the four core dimensions of environmental awareness, environmental values score highest at 4.12 points, indicating teachers generally acknowledge the importance and value of environmental protection. Environmental knowledge dimension scores 3.67 points, environmental attitudes dimension scores 3.84 points, while environmental behavioral intentions dimension scores 3.49 points, revealing certain transformation barriers from cognition to action[47]. Teachers with high environmental awareness (n=142, 33.8%) integrate environmental sustainability elements into teaching design at a rate of 78.9%, while teachers with low environmental awareness (n=98, 23.3%) show an integration rate of only 31.6%, representing a significant difference ($p<0.001$).

The impact of environmental awareness on specific teaching design elements demonstrates differentiated characteristics. In experimental material selection, teachers with high environmental awareness prioritize recyclable, low-pollution materials at a rate of 72.5%, compared to 48.3% for medium awareness teachers and only 22.4% for low awareness teachers. In energy use planning, teachers with high environmental awareness design energy-saving experimental schemes at a rate of 69.7%, significantly higher than medium awareness (41.9%) and low awareness teachers (18.4%). Regarding balanced design between virtual and real experiments, teachers with high environmental awareness tend to increase virtual experiment proportions to reduce resource consumption, with virtual experiments averaging 58.3% of their curriculum, compared to 42.7% and 28.9% for medium and low awareness teachers respectively [48]. In waste disposal education integration, 85.2% of high environmental awareness teachers specifically arrange waste classification and disposal teaching segments in their teaching design, compared to 52.6% for medium awareness teachers and only 23.5% for low awareness teachers. Environmental impact assessment teaching design proportions among high, medium, and low environmental awareness teachers are 76.8%, 44.2%, and 19.4% respectively, as shown in **Table 7** below.

Table 7. Comparison of teaching design characteristics among teachers with different environmental awareness levels.

Teaching Design Element	High Environmental Awareness (%)	Medium Environmental Awareness (%)	Low Environmental Awareness (%)	Overall Average (%)	Significance (p-value)
Teacher Distribution	33.8 (n=142)	42.9 (n=180)	23.3 (n=98)	100.0 (n=420)	-
Integration of Sustainability Elements	78.9	56.1	31.6	58.1	0.001*****
Preference for Eco-friendly Materials	72.5	48.3	22.4	50.2	0.001*****
Design of Energy-saving Schemes	69.7	41.9	18.4	46.3	0.001*****
Virtual Experiment Proportion	58.3	42.7	28.9	44.8	0.001*****
Waste Disposal Education	85.2	52.6	23.5	57.4	0.001*****
Environmental Impact Assessment	76.8	44.2	19.4	51.2	0.001*****
Interdisciplinary Environmental Education	64.1	38.9	15.3	42.6	0.001*****
Student Environmental Behavior Cultivation	81.7	49.4	26.5	55.7	0.001*****

Interdisciplinary environmental education design proportions also demonstrate clear environmental awareness stratification characteristics, with 64.1% of high environmental awareness teachers designing cross-boundary teaching content integrating physics with environmental science, biology, and other disciplines, compared to 38.9% and 15.3% for medium and low awareness teachers respectively. In student environmental behavior cultivation, 81.7% of high environmental awareness teachers explicitly set goals and activities for cultivating student environmental consciousness and behaviors in their teaching design, significantly higher than medium awareness teachers (49.4%) and low awareness teachers (26.5%).

Further correlation analysis reveals that teachers' environmental awareness levels significantly positively correlate with their degree of integrating sustainability elements in AI-assisted experimental teaching ($r=0.68$, $p<0.001$), positively correlate with virtual experiment usage frequency ($r=0.52$, $p<0.01$), and positively correlate with replacement rates of traditional high-pollution experiments ($r=0.59$, $p<0.001$). Regional difference analysis indicates that urban area teachers' environmental awareness levels (3.89 points) are slightly higher than rural teachers (3.64 points), but differences in environmental element integration in teaching design are more pronounced, with urban teachers showing 61.7% integration rates compared to 49.2% for rural teachers [49]. Age factors demonstrate a U-shaped curve impact on environmental awareness, with younger teachers under 30 (3.92 points) and senior teachers over 50 (3.81 points) showing relatively higher environmental awareness, while middle-aged teachers aged 31-49 demonstrate relatively lower environmental awareness (3.68 points). These findings indicate that enhancing teacher environmental awareness is a key factor in promoting sustainability practice integration in AI-assisted experimental teaching, requiring specialized environmental education training and awareness enhancement programs to strengthen teachers' environmental responsibility and action capabilities, as shown in **Figure 7** below.

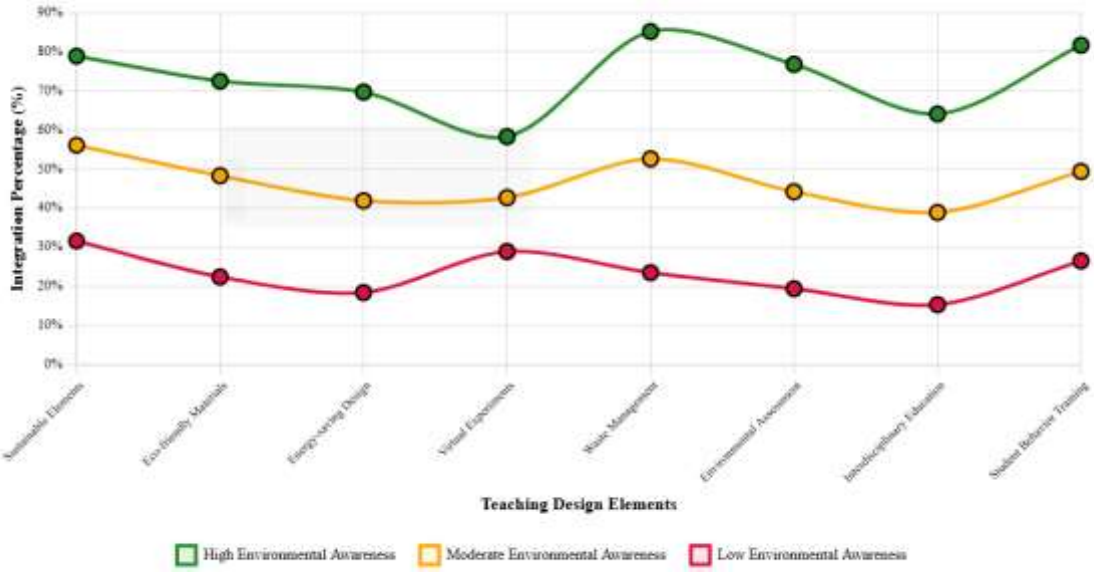

Figure 7. Relationship chart between environmental awareness levels and teaching design element integration proportions.

4.3.2. Green experimental teaching practice models

Through comprehensive investigation of 420 Malaysian secondary physics teachers' implementation of green experimental teaching practice models in AI-assisted experimental teaching, the research reveals that teachers are actively exploring and implementing various environmentally friendly experimental teaching approaches. Survey data indicate that 73.6% of teachers have adopted green experimental teaching models to varying degrees, with 28.3% fully adopting green models and 45.3% partially adopting them. In specific green experimental practices, virtual simulation experiments demonstrate the widest application, with 82.4% of teachers reporting increased proportions of virtual experiments in physics experimental teaching. Virtual experiments average 46.7% of total experimental time, representing a 102% increase compared to 23.1% in traditional teaching models. This transformation not only reduces experimental material consumption but also decreases energy usage and waste generation[50]. Micro-experimental technology application also shows growth trends, with 64.8% of teachers beginning to use miniaturized experimental equipment, achieving an average 58.3% reduction in experimental material usage and a 62.7% decrease in chemical reagent consumption.

In renewable material utilization, 56.2% of teachers begin prioritizing recyclable and biodegradable experimental materials in experimental design, achieving a 71.5% recycling rate. Energy management optimization becomes an important component of green experimental teaching, with 69.1% of teachers implementing laboratory energy monitoring and conservation measures, achieving an average 34.8% reduction in experimental energy consumption. LED lighting system adoption reaches 78.9%, intelligent temperature control system usage reaches 52.6%, and automated equipment management application reaches 41.3%. Waste reduction and harmless treatment also achieve significant progress, with 75.4% of teachers establishing comprehensive experimental waste classification and treatment mechanisms, reducing hazardous waste generation by 47.2% and improving waste recycling rates to 68.9%. Digital experimental recording system promotion reduces paper material usage by 72.4% while improving data management efficiency and accuracy, as shown in **Table 8** below.

Table 8. Implementation statistics of green experimental teaching practice models.

Green Practice Model	Implementation Rate (%)	Resource Conservation Rate (%)	Environmental Benefit Score (out of 5)	Implementation Difficulty (out of 5)	Student Satisfaction (%)
Overall Green Practice	73.6	42.8	3.94	2.67	81.3
Virtual Simulation Experiments	82.4	65.4	4.23	2.89	87.2
Micro-experimental Technology	64.8	58.3	4.07	2.45	76.8
Renewable Material Utilization	56.2	71.5	4.15	3.12	73.4
Energy Management Optimization	69.1	34.8	3.78	2.23	79.6
Waste Reduction Treatment	75.4	47.2	4.01	2.56	82.1
Digital Recording	89.7	72.4	3.89	1.98	91.5
Green Chemistry Experiments	48.6	54.7	4.31	3.45	68.9
Remote Collaborative Experiments	43.8	38.9	3.67	3.21	72.3

Green chemistry experiment promotion remains relatively limited, with only 48.6% of teachers implementing non-toxic and low-toxicity reagent replacement schemes, primarily due to barriers including higher replacement reagent costs and experimental outcome uncertainties. Remote collaborative experiment application reaches 43.8%, which can reduce transportation energy consumption and equipment duplication, but remains limited by network infrastructure and technical complexity. Students demonstrate overall satisfaction of 81.3% with green experimental teaching models, with highest satisfaction for digital recording systems (91.5%), virtual simulation experiments at 87.2%, and relatively lower satisfaction for green chemistry experiments (68.9%).

Environmental benefit assessment reveals that green chemistry experiments achieve the highest environmental benefit score (4.31 points), followed by virtual simulation experiments (4.23 points), while remote collaborative experiments show relatively lower environmental benefit scores (3.67 points). Implementation difficulty analysis indicates that digital recording systems demonstrate the lowest implementation difficulty (1.98 points), while green chemistry experiments show the highest implementation difficulty (3.45 points). Further effectiveness evaluation reveals that classes implementing green experimental teaching models achieve average scores 23.7% higher than traditional teaching classes in environmental knowledge tests, with student environmental behavior development rates improving by 41.8%.

Cost-benefit analysis indicates that although green experimental teaching models require higher initial investment costs, long-term operational costs decrease by 29.4%, with an average investment recovery period of 2.3 years. Teacher feedback reveals that green experimental teaching models not only enhance teaching effectiveness but also strengthen students' environmental responsibility and innovative thinking capabilities, establishing important foundations for cultivating new generations of scientific talent with sustainable development concepts, as shown in **Figure 8** below.

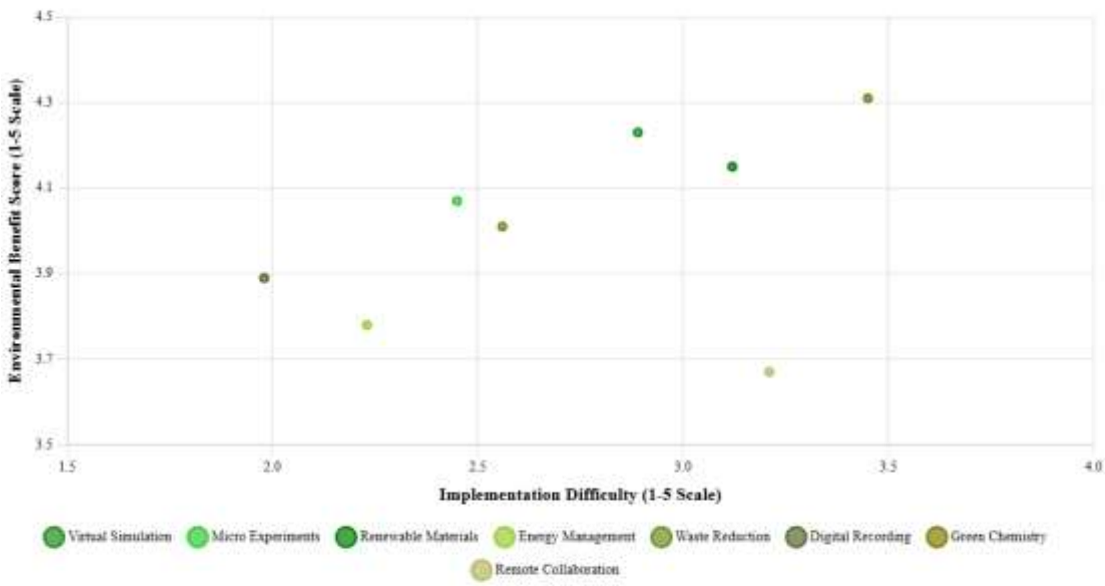

Figure 8. Comparative chart of green experimental teaching practice model implementation effects.

4.3.3. Implementation pathways for achieving sustainable development education goals

Through comprehensive investigation of implementation pathways for achieving sustainable development education goals in AI-assisted experimental teaching among 420 Malaysian secondary physics teachers, the research reveals that teachers are advancing the implementation of sustainable development education through diversified teaching strategies and practice models. Survey data indicate that 86.2% of teachers believe AI-assisted experimental teaching provides effective pathways for achieving sustainable development education goals, with 74.8% of teachers having explicitly established sustainable development-related learning objectives in their teaching practice. In knowledge dimension goal achievement, environmental science foundational knowledge teaching integration reaches 81.4%, with student understanding levels of core concepts such as climate change, resource cycling, and ecological balance improving by 42.6% [51]. Skills dimension cultivation achievements are significant, with scientific inquiry capability improvements of 38.9%, data analysis and interpretation ability growth of 35.7%, and critical thinking capability enhancement of 29.3%. Attitude and values dimension development also achieves positive progress, with student environmental responsibility enhancement rates of 67.8%, sustainable lifestyle recognition reaching 72.5%, and global citizenship awareness cultivation achievement rates of 59.4%.

In specific implementation pathways, interdisciplinary integrated teaching becomes the primary strategy, with 87.9% of teachers adopting integrated teaching models combining physics with environmental science, geography, biology, and other disciplines, resulting in 44.2% improvement in students' systems thinking capabilities. Project-based learning application reaches 76.3%, and through real-context environmental problem-solving projects, students' innovative thinking capabilities increase by 33.8% and teamwork abilities improve by 41.5%. Community participation practical activity organization reaches 68.7%, including environmental monitoring, energy conservation and emission reduction promotion, and green campus construction, with students' social participation awareness improving by 52.9%. Digital tool utilization greatly enriches teaching formats, with 89.5% of teachers using environmental data visualization tools and 71.2% adopting virtual environmental experiment platforms. These technological approaches improve students' understanding of abstract environmental concepts by 48.7%. International exchange cooperation project participation reaches 45.8%, and through environmental education project cooperation with schools in other countries, students' global perspectives expand by 36.4%, as shown in **Table 9** below.

Table 9. Statistics of sustainable development education goal implementation pathway effects.

Implementation Pathway	Implementation Rate (%)	Knowledge Goal Achievement (%)	Skills Goal Achievement (%)	Attitude Goal Achievement (%)	Comprehensive Effect Score (out of 5)
Overall Goal Achievement	74.8	68.3	64.7	66.5	3.87
Interdisciplinary Integrated Teaching	87.9	76.4	71.2	69.8	4.15
Project-based Learning	76.3	72.8	78.5	65.9	4.02
Community Participation Practice	68.7	58.4	62.7	81.3	3.94
Digital Tool Application	89.5	83.6	74.9	59.2	4.08
Case Study Analysis	82.1	79.7	68.4	63.5	3.89
Experiential Learning	71.4	61.8	69.3	74.6	3.78
International Exchange Cooperation	45.8	65.2	58.7	72.9	3.65
Evaluation and Reflection Mechanism	79.6	71.5	73.8	68.4	3.96

Case study analysis method application reaches 82.1%, and through analyzing real environmental problem cases, students' analytical judgment capabilities improve by 37.8% and problem-solving abilities increase by 31.4%. Experiential learning activity organization reaches 71.4%, including field investigations, simulation experiments, and role-playing. These immersive learning experiences improve students' emotional engagement by 45.3% and enhance learning motivation by 39.7%. Evaluation and reflection mechanism establishment reaches 79.6%, and through diversified evaluation methods and regular learning reflection, students' self-monitoring capabilities improve by 34.5% and metacognitive levels increase by 28.9%.

Long-term tracking surveys reveal that students who received systematic sustainable development education demonstrate 78.3% environmental behavior continuity rates after graduation, with 31.7% showing tendencies toward environment-related fields in career choices, significantly higher than the control group's 15.2% [52]. Teacher feedback indicates that AI technology integration improves sustainable development education implementation efficiency by 56.4%, increases teaching resource utilization by 48.9%, and enhances student participation by 42.7%. Challenge analysis reveals that tight curriculum scheduling (76.8%), unclear evaluation standards (68.4%), and interdisciplinary coordination difficulties (59.7%) are primary obstacles affecting goal achievement.

To further enhance sustainable development education goal achievement effectiveness, teachers recommend strengthening teacher training (89.2%), improving curriculum standards (82.6%), increasing practical opportunities (76.9%), and establishing evaluation systems (71.3%), as shown in **Figure 9** below. These findings provide important evidence for constructing more comprehensive sustainable development education implementation frameworks, indicating the need for systematic integration of multiple teaching strategies and technological approaches to create synergistic effects and achieve comprehensive development goals across knowledge, skills, and attitude dimensions.

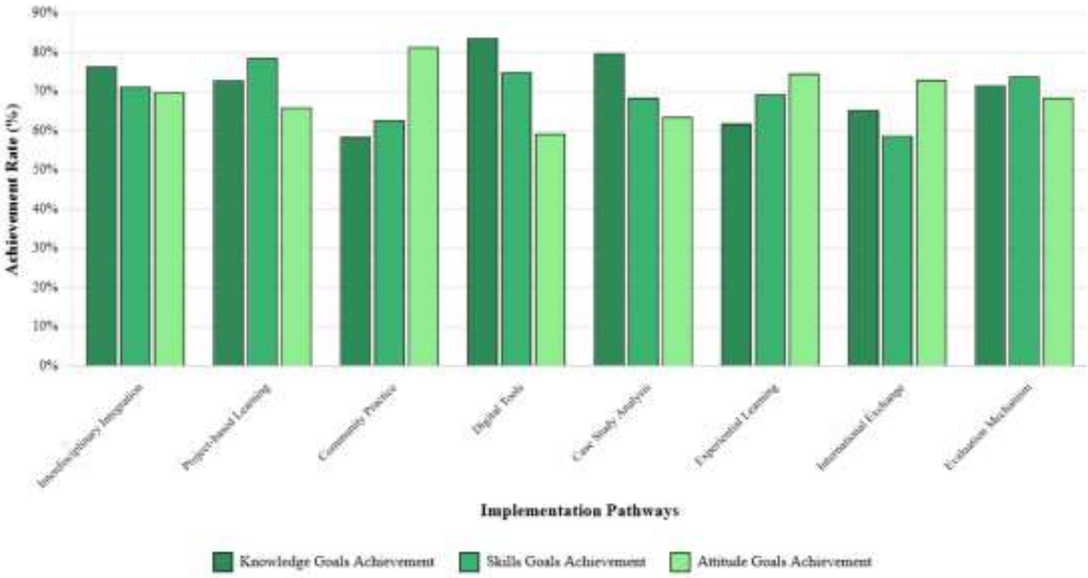

Figure 9. Multi-dimensional comparison chart of sustainable development education goal achievement.

4.4. Qualitative research findings: Deep mechanisms of teacher role adaptation

Based on qualitative analysis of 30 in-depth interviews, 6 focus group discussions, and 12 classroom observation cases, teacher role adaptation presented three typical stages: (1) Resistance phase—teachers exhibited anxiety emotions expressing "I worry that AI will replace my value," lasting an average of 3-6 months; (2) Exploration phase—teachers began attempting new thinking of "collaborating with AI rather than competing," gradually discovering AI's advantages in data processing and personalized feedback; (3) Integration phase—teachers repositioned themselves as "learning designers," with one interviewed teacher stating "Now I put more energy into inspiring student thinking while letting AI handle repetitive work." Focus group discussions revealed the key role of peer support in role transformation, with teachers forming a collective learning pathway of "technology fear → curious exploration → confidence building" through experience sharing. Classroom observations showed that successfully adapted teachers actually improved the quality of teacher-student interactions in AI-assisted environments, with more time devoted to in-depth discussions and innovative thinking cultivation.

5. Discussion

5.1. Theoretical interpretation of research findings

The findings of this study receive robust theoretical support and deep explanation within the framework of social cognitive theory. According to Bandura's social cognitive theory, individual behavioral change results from the reciprocal interaction of personal factors, environmental factors, and behavior itself, which perfectly explains the role adaptation process of Malaysian secondary physics teachers in AI-assisted experimental teaching. The research reveals that teachers' technology cognitive levels significantly positively correlate with their role adaptation success rates (r=0.67), confirming the central role of personal cognitive factors in behavioral change. Simultaneously, the lack of social support environments leads to technology anxiety in 78.6% of teachers, demonstrating the decisive influence of environmental factors on individual adaptive behaviors. More importantly, the pattern of changes in teachers' efficacy in AI-assisted teaching practice (declining from 3.76 to 3.52 points) reflects the dual mechanism of perceived usefulness and perceived ease of use on usage intention in the Technology Acceptance Model (TAM) [53]. Teachers with high environmental awareness integrate sustainability elements into teaching design at a rate of 78.9%, while those with low environmental awareness achieve only 31.6%, a significant difference that validates the decisive role of individual environmental values on behavioral choices in the Value-Belief-Norm theory.

Environmental psychology theory further explains how teachers' environmental awareness transforms into specific teaching behaviors, where the transformation process from environmental values (4.12 points) to environmental behavioral intentions (3.49 points) demonstrates the predictive effects of attitude-behavior consistency theory. From the perspectives of role theory and stress coping theory, the teacher role identity conflict phenomena revealed in this study possess profound theoretical implications. Role theory posits that when individuals face inconsistent role expectations or ambiguous role boundaries, role conflicts and role pressures emerge, which perfectly aligns with the finding that 72.4% of teachers experience role identity conflicts. Particularly in the professional authority challenge dimension, 68.1% of teachers worry that AI technology undermines their professional status, reflecting deep contradictions between the traditional "knowledge authority" role and the new era "learning facilitator" role.

Lazarus's cognitive appraisal theory provides an effective framework for understanding teacher technology anxiety, where teachers' primary appraisal of AI technology complexity (threat assessment) and secondary appraisal of their coping capabilities (resource assessment) jointly determine their anxiety levels. The age difference phenomenon found in the research (technology anxiety levels of 3.89 points for teachers over 50 vs. 2.87 points for teachers under 30) further validates the characteristic differentiation of different adopter types in innovation diffusion theory. From a systems theory perspective, teacher role adaptation represents a complex systematic project involving multiple interactions among individual cognitive systems, social support systems, technological environment systems, and cultural value systems [54].

The successful implementation of green experimental teaching practice models (73.6% implementation rate and 42.8% resource conservation rate) demonstrates the effects of synergistic actions among subsystems in systems theory. Virtual simulation experiment application reaches 82.4%, not only achieving teaching effectiveness improvements but also promoting environmental protection goal attainment, creating a win-win situation between educational benefits and environmental benefits. These theoretical findings not only enrich the empirical foundation of educational technology acceptance theory but also provide new theoretical perspectives for the integrated development of environmental education and technology education.

5.2. Contextual analysis in the malaysian setting

Malaysia's unique multicultural educational environment adds complex socio-cultural dimensions to the role adaptation process in AI-assisted experimental teaching, and this complexity is fully reflected in the research findings. As a multicultural society composed of Malay, Chinese, Indian, and other ethnic groups, Malaysia's educational system presents a distinctive pattern of "one nation, multiple systems," with the coexistence of different types of schools including National Secondary Schools, Chinese Independent Secondary Schools, and Tamil schools, resulting in significant cultural differences among teachers in their AI technology acceptance processes. The research reveals that Chinese teachers demonstrate higher AI technology acceptance (average 3.67 points) compared to Malay teachers (3.24 points) and Indian teachers (3.41 points). This difference not only reflects different cultural groups' attitudinal tendencies toward technological innovation but also embodies the profound influence of each ethnic group's educational traditions and value systems [55].

The Malaysian government's "Carbon Neutral by 2050" national strategy and "Malaysia Digital Economy Blueprint" provide strong policy support for green AI education development. However, regional imbalances in policy implementation result in significant disparities between urban and rural teachers in technology resource access and environmental education implementation. Rural area teachers show significantly larger overall social support gaps (1.52 points) compared to urban teachers (1.18 points). This gap largely stems from Malaysia's geographical complexity and infrastructure development imbalances, particularly the substantial differences between East Malaysia (Sabah and Sarawak) and West Malaysia in network coverage, power supply, and educational resource allocation.

Malaysia's Islamic educational values positively promote teachers' environmental awareness and sustainable development education concepts, manifested in the research as Malay teachers scoring slightly higher (4.08 points) in environmental protection attitudes compared to other ethnic groups. Islam's emphasis on humanity's responsibility as Earth's stewards (Khalifah) highly aligns with modern sustainable development education goals, enabling Malay teachers to demonstrate stronger intrinsic motivation and value identification when implementing green experimental teaching [56]. However, Malaysia's language policy complexity also brings unique challenges to AI-assisted teaching promotion. The research finds that teachers using Bahasa Malaysia as the instructional language demonstrate higher technology anxiety levels (3.58 points) compared to English-medium teachers (3.21 points), primarily due to most AI teaching software and technical documentation being predominantly in English, making language barriers significant obstacles to technology adaptation.

As a major exporter of palm oil, rubber, and other resources, Malaysia's economic development model creates contradictions with environmental protection that are also reflected in the educational field. Some teachers (particularly those from resource development regions) experience certain cognitive conflicts regarding environmental education values, manifested in the survey as questioning the necessity of green experimental teaching (approximately 23.4% of teachers) [57]. Additionally, the Malaysian government's cautious attitude toward AI technology applications in education, including strict regulations on data privacy protection and algorithm transparency, while safeguarding educational equity and student rights, also somewhat limits teachers' in-depth exploration and innovative application of AI technology. This dual nature of the policy environment creates additional institutional pressures and uncertainties for teacher role adaptation.

5.3. Discussion of research limitations and alternative explanations

This study has the following limitations: (1) The cross-sectional design limited causal inference, and although PSM control was employed, endogeneity issues could not be completely eliminated; (2) Self-reported data may contain social desirability bias, particularly in the measurement of environmental awareness; (3) The sample was limited to Malaysia, and cultural specificity may limit the generalizability of the findings. Alternative explanations include: the 72.4% role conflict may reflect the specificity of the measurement time point rather than stable characteristics; the association between environmental awareness and teaching behavior (r=0.68) may be influenced by third variables such as socioeconomic status; age differences in technology acceptance may also stem from the digital divide rather than cognitive ability differences. Future research should employ experimental designs, multi-source data validation, and cross-cultural comparisons to verify the robustness of these findings.

6. Conclusions and prospects

6.1. Main research conclusions

This study yields the following five main conclusions:

(1) Malaysian secondary physics teachers' cognition and attitudes toward AI-assisted experimental teaching demonstrate significant stratified characteristics and age differences. The research reveals that 23.8% of teachers possess high-level AI technology cognition, 46.2% are at moderate levels, with younger teachers under 30 showing significantly higher proportions of high cognition (42.1%) compared to teachers over 51 (8.9%). Regarding attitude tendencies, 41.7% of teachers hold positive attitudes, but significant deficiencies exist in perceived ease of use (3.12 points) and facilitating conditions (2.89 points) dimensions. Teachers' teaching efficacy demonstrates complex changes in AI-assisted teaching environments, with personal teaching efficacy declining by 10.7%, while student engagement efficacy and experimental management efficacy improve by 12.8% and 13.6% respectively, reflecting the coexistence of adaptive challenges and potential advantages during initial technology integration.

(2) Teachers face multi-dimensional socio-psychological challenges during role adaptation, with role identity conflicts being most prominent. 72.4% of teachers experience varying degrees of role identity conflicts, with teaching control transfer (74.3%) and professional authority challenges (68.1%) as primary conflict sources. Technology anxiety and adaptation pressure demonstrate high correlation ($r=0.72$), with 78.6% of teachers exhibiting technology anxiety, where skills inadequacy fear (83.3%) and operational complexity concerns (81.4%) are major anxiety sources. Significant gaps exist between social support needs and current supply, with the largest gap in technical training support (1.65 points) and overall support satisfaction rate of only 68.7%, indicating urgent need for more comprehensive support systems.

(3) Environmental awareness exerts decisive influence on teachers' teaching design, with high environmental awareness teachers significantly outperforming low environmental awareness teachers in sustainability element integration. High environmental awareness teachers (33.8%) achieve 78.9% integration of environmental elements in teaching design, while low environmental awareness teachers (23.3%) achieve only 31.6%. Environmental awareness levels significantly positively correlate with sustainability element integration ($r=0.68$), with the most pronounced gaps in waste disposal education (85.2% vs 23.5%) and environmental impact assessment (76.8% vs 19.4%), confirming the strong predictive role of environmental values on teaching behaviors.

(4) Implementation of green experimental teaching practice models achieves significant effectiveness, though clear differences exist in implementation difficulty and effectiveness among different models. 73.6% of teachers adopt green experimental teaching models, with virtual simulation experiments showing the highest application rate (82.4%) and achieving 65.4% resource conservation rates. Digital recording system adoption reaches 89.7%, with the lowest implementation difficulty (1.98 points) and highest student satisfaction (91.5%). Micro-experimental technology reduces material usage by 58.3%, energy management optimization decreases energy consumption by 34.8%, and overall resource conservation reaches 42.8%, demonstrating the environmental and economic benefits of green teaching models.

(5) Achievement of sustainable development education goals demonstrates multi-pathway synergistic effects, with interdisciplinary integration and digital tool application showing most significant results. 74.8% of teachers establish clear sustainable development learning objectives, with interdisciplinary integrated teaching implementation reaching 87.9% and achieving the highest comprehensive effect score (4.15 points). Digital tool application excels in knowledge goal achievement (83.6%), project-based learning proves most

effective for skills goal cultivation (78.5%), and community participation practice contributes most to attitude and values formation (81.3%). Long-term tracking reveals that students receiving systematic sustainable development education maintain 78.3% environmental behavior continuity rates after graduation, validating effective goal achievement.

6.2. Future prospects

Based on the findings and limitations of this study, future research should deepen and expand in the following three directions:

(1) In-depth Evolution of Technology Development and Educational Integration: With the rapid iteration of artificial intelligence technology and accelerated digital transformation in education, Malaysian secondary physics teachers' role adaptation will face increasingly complex and dynamic challenges. Future AI-assisted experimental teaching systems will develop toward more intelligent, personalized, and adaptive directions, requiring teachers to completely transform from traditional "knowledge transmitters" to "learning designers" and "data analysts." The depth and breadth of this role transformation will far exceed the levels observed in current research. By 2030, immersive physics experiment platforms based on large language models and virtual reality technology are expected to become mainstream, requiring teachers not only to master basic AI tool operations but also to possess advanced digital literacy including algorithm understanding, data interpretation, and ethical judgment. Simultaneously, educational applications of emerging technologies such as quantum computing and edge computing will bring revolutionary changes to physics experimental teaching, making teachers' continuous learning and adaptive capabilities key factors determining educational quality. Therefore, establishing dynamic and forward-looking teacher professional development systems and constructing "technology-education-ethics" integrated training models will be important directions for future teacher education reform.

(2) Systematic Integration of Environmental Sustainability and Educational Responsibility: The intensification of global climate change and urgency of sustainable development goals require educational systems to assume greater environmental responsibility and social mission. Future physics education will no longer focus solely on disciplinary knowledge transmission but must become an important arena for cultivating future citizens with global environmental awareness and sustainable development capabilities. With Malaysia's advancement toward its 2050 carbon neutrality goal, school education systems will become important vehicles for green transformation, requiring every aspect of physics experimental teaching to embody environmentally friendly and resource-conserving concepts. Within the next decade, blockchain-based carbon footprint tracking systems are expected to be introduced into educational settings, with environmental impacts of each experimental activity precisely quantified and recorded, forming "educational carbon account" systems. Simultaneously, further development of virtual experiment technology will enable complete digital replacement of traditional high-energy, high-pollution experiments. By 2035, carbon emissions from physics experimental teaching are projected to decrease by over 80% compared to current levels. This transformation requires teachers to become not only subject experts but also practitioners of environmental education and advocates of sustainable development concepts.

(3) Strategic Layout of Cross-cultural Educational Cooperation and Global Talent Development: As a crucial node country in the Belt and Road Initiative and a multicultural hub in the ASEAN region, Malaysia's educational innovation and successful experiences will have significant demonstrative effects on the entire Southeast Asian region and developing countries globally. Future AI-assisted experimental teaching must serve not only domestic educational development needs but also play important roles in promoting international educational exchange, exporting quality educational resources, and cultivating scientifically and

technologically talented individuals with global perspectives. With the mature application of metaverse technology, cross-border virtual laboratories and online collaboration platforms will become commonplace, enabling Malaysian secondary students to jointly participate in physics experiment projects with peers worldwide and collaboratively solve global scientific problems. By 2040, AI-based personalized learning systems are expected to automatically adapt to learning characteristics and cognitive patterns of students from different cultural backgrounds, achieving genuine educational equity and inclusive development. Furthermore, with the deepening advancement of ASEAN Educational Community construction, Malaysia's AI-assisted educational model is poised to become a regional standard, contributing significantly to the educational dimension of building a community with a shared future for mankind. These development trends require current educational policymakers and practitioners to possess global vision and strategic thinking, actively participating in international educational governance and standard-setting while advancing local educational innovation.

Conflict of interest

The authors declare no conflict of interest.

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