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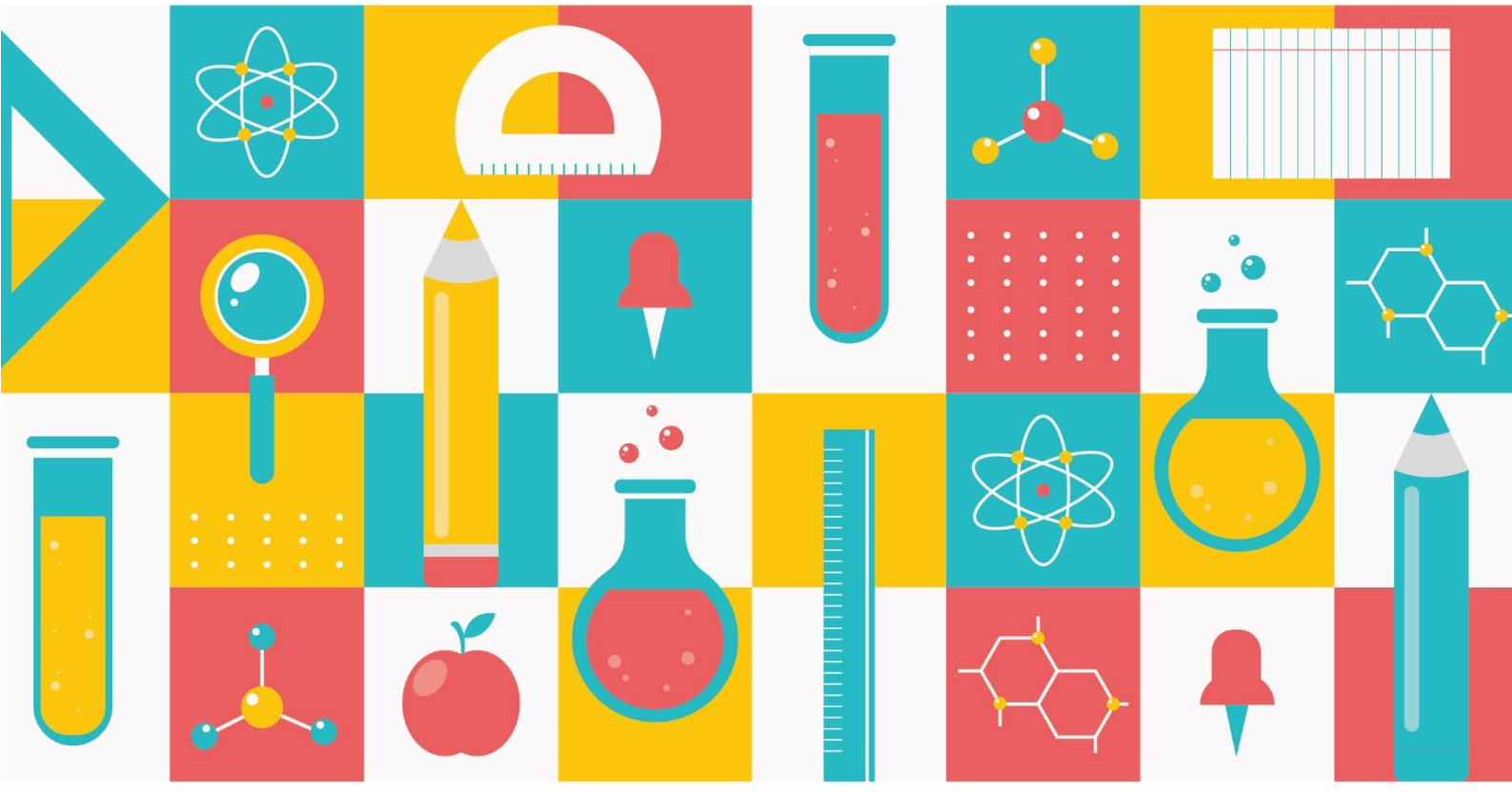

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Artificial Intelligence in Higher Education: A Case Study of Faculty Teaching Methodologies at a Private University

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Abstract

This qualitative case study investigates faculty perspectives on artificial intelligence (AI) integration within a private university context, examining pedagogical, administrative, and ethical implications. Data collected through semi-structured interviews with faculty across four disciplines revealed ambivalent yet cautiously optimistic attitudes. Participants acknowledged AI's potential to enhance personalized learning and reduce bureaucratic burdens through automation. However, three critical barriers emerged: (1) insufficient institutional technological infrastructure, (2) lack of systematic faculty training programs, and (3) unresolved ethical dilemmas surrounding data privacy, algorithmic bias, and academic integrity. Notably, while faculty welcomed AI as a supplemental tool, they unanimously emphasized the irreplaceable role of human judgment in pedagogy. The study contributes to emerging scholarship on educational technology by proposing an ethical implementation framework that reconciles efficiency gains with core academic values. Practical recommendations address policy development and targeted professional training to support responsible adoption. These findings offer timely insights for higher education institutions navigating AI integration while preserving pedagogical integrity and equity considerations.

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Introduction

The wave of artificial intelligence is a radical departure from learning and administration systems in higher education (Zawacki-Richter et al., 2019; Mohamed et al., 2022; Cardona et al., 2023; Drozdowski & Johnson, 2023). Redefinition of the education ecosystem has unfolded in the form of digital technology through adaptive learning platforms, intelligent tutoring systems, and learning analytics that provide personalized learning pathways and operational efficiencies (Crompton & Burke, 2023: Wang et al., 2023). Moreover, the emerging technologies, VR/AR, robotics, and machine learning algorithms, providing possibilities for student-centered immersive learning environments for scalable education, are set to give new dimensions (Wang et al., 2023). These advances could summarize global education objectives, such as realizing UN SDG #4 or ensuring inclusive and equitable quality education (UNESCO, 2023). It will complement ethical principles, including transparency, fairness, and accountability, in augmenting AI with the desired role of boosting the achievement of the other global goals. The study results further emphasized other concerns besides data security, like privacy, justice issues, and possibly replacing human interaction and learning with machine and robot interaction (Pedro et al., 2019; Chen, 2023).

From these approaches, the findings showed that the faculty members played a central role in bridging the change as they impacted the quest for AI in the pedagogical practices, perhaps hinging on the technologies used and their effectiveness in enhancing learning outcomes (Seo et al., 2021; Sharawy, 2023). This study adopted a qualitative and quantitative case study approach to exploring the university-level faculty's perceptions toward pedagogical technology integration.

This inquiry contributed to the general discourse on AI for higher education by systematically investigating its role in furthering global teaching and the infusion of critical thinking, social responsibility, and sustainability capabilities. The research provided legitimate empirics to the administration to implement AI and related technologies while maintaining pedagogical integrity and ethical standards. This aligned very well with the essential UN framework within which sustainability and global citizenship education occur, emphasizing responsible and inclusive learning approaches to tackling global challenges (UNESCO, 2023).

This study effectively bridged the practice-theory gap in AI education research, giving way to applied evidence from the investigation conducted on faculty perspectives. This work followed the United Nations SDGs and Global Citizenship Education framework, generating evidence-based recommendations to position emerging technologies at the vanguard of supportive decision-making for creating inclusive and sustainable educational experiences. The findings contribute to the expanding body of knowledge regarding responsible AI adoption

in higher education, emphasizing the balance between technological innovation and fundamental teaching principles (Sharawy, 2023).

This investigation at this university examined five primary research questions:

1. How do faculty at this university perceive the role of AI in enhancing teaching methodologies?
2. What challenges or barriers have been encountered in integrating AI into the curriculum and teaching practices?
3. In what ways has AI transformed administrative processes related to teaching and learning at this university?
4. How do faculty envision the future of AI in higher education, especially in their field of expertise?
5. What ethical or practical concerns did faculty have regarding the widespread adoption of AI in higher education?

These questions guided the mixed-methods investigation of AI integration within a private university's specific institutional context, allowing for the examination of both the practical implementation challenges and broader implications for higher education.

Literature Review

The rapid integration of AI into higher education sparked considerable academic discourse and institutional debate (UNESCO IESALC, 2023; Drozdowski & Johnson, 2023; Milgrom-Elcott, 2023). The transformation of teaching methodologies, learning processes, and pedagogical frameworks emerged as central themes in contemporary research. Intelligent tutoring systems, adaptive learning platforms, and academic analytics demonstrated potential for educational transformation through personalized learning experiences, automated feedback mechanisms, and data-driven insights (Humble & Mozelius, 2022; Crompton & Burke, 2023). Faculty members emerged as primary drivers of AI adoption and critical mediators of its successful integration into pedagogical methodologies and student outcome achievement. Literature has identified notable challenges in implementing technology within educational settings. Key ethical issues have reportedly arisen, most notably efforts toward data privacy, algorithmic bias, and socio-psychological dimensions affecting individuals who are part of education (Nasir et al., 2022; Chen, 2023). Academic discussions of the conference confronted contradictions about technological integration and human interaction within learning spaces and raised crucial inquiries about how AI could complement traditional teaching methods (Pedro et al., 2019).

AI for Personalized Learning

Recent literature illustrates that AI improves personalization and fosters the emergence of automated feedback mechanisms (Mollick & Mollick, 2023). Technological advancement corresponds with Vygotsky's (1978) Zone of Proximal Development theory, creating an adaptive learning environment that caters to individual learners' specific needs (Mohamed et al., 2022). While Zawacki-Richter et al. (2019) drew attention to the positive effects of AI on personalized learning systems, they mainly focused on the advantages absent the challenges relating to implementation.

Implementation Challenges

Several integration barriers include technological gaps, institutional inertia, and the ethical domain: all expounded sufficiently in the works of Shonubi and Talwar (2023). As proposed, there is an urgent and great need for solid regulatory frameworks addressing data security and privacy for AI educational technologies (UNESCO IESALC, 2023). Faculty struggled with lacking opportunities for sufficient infrastructure and training (Sharawy, 2023). The situation was aggravated by boundless financial resources and somewhat by the normalizing of school strategies (Criddle & Staton, 2022); Flores-Vivar and García-Peñalvo (2023) took mainstream studies on how the integration of AI may reinforce preexistent inequities among marginalized students.

Administrative Efficiency Enhancement

One reason is that AI can improve the administration and automation of routine yet necessary activities like approval, scheduling, and monitoring. As a result, campus staff freed up more time to focus on teaching and tutoring students directly (Cardona et al., 2023; Ladd, 2023; Milgrom-Elcott, 2023; Ellis, 2024). Our review agrees with other research indicating that AI augments administration workflow and decision-making at the higher education level (Seo et al., 2021; Drozdowski & Johnson, 2023).

Future Visions of AI

Authors investigate by literature the possible transformation of higher education, with a clear sense of personalization, assistance in research, and in some other areas where efficiency is desired in relation to higher education (Crompton & Burke, 2023; Shonubi, 2023; Rahiman & Kodikal, 2024). Faculty members supported technology in a believe-to-be supportive role, provided they were supplements to human instruction and not placed in the role to entirely replace that instruction (Wang et al., 2023). Most of the research based on

developing countries, especially India, transcends the promises of AI as an ameliorative force in education, dictated by the inequitable moment later conjugated on disabling access to technology and hitting the barrier of the education infrastructure industry (Jaiswal & Arun, 2021). Briefly put US research presentation on globalization occurs together with AI and the integration of a constantly evolving cultural and educational milieu.

Ethical Considerations

Professional and ethical considerations became central themes within the literature discussion, which includes data privacy issues and fair AI algorithms to users as effects on the socio-psychological well-being of the stakeholders in education. AI systems' management of personal data and reinforcement of pre-existing biases were also discussed during research (Zeide, 2019; Nasir et al., 2022). UNESCO's report on generative AI highlighted potential and existing risks related to data privacy and called for regulation that prioritizes human autonomy, inclusion, and cultural identity in using AI (Murgia & Staton, 2023; Ellis, 2024; UNESCO, 2023). The development of Generative AI (GenAI) brought up particular kinds of education apart from conventional AI uses, namely, creating teaching materials and individualized learning. Okaiyeto, Bai, and Xiao (2023) supported the calls that have pointed to the need for curriculum modifications that integrate GenAI responsibly and in a way that does not compromise the learning goals. Bias was presented in the literature as one of the most pressing issues affecting the use of algorithms in education regarding vulnerable students and compliance with United Nations Sustainable Development Goal 4 with reference to inclusive learning. Through this literature synthesis and consideration of this university's specific context, five research questions were developed to guide our investigation. Five questions emerged from both the identified gaps in current research and the practical needs of the institution:

RQ1 Faculty Perception and Enhancement:

Recent studies highlight the importance of understanding faculty perspectives on AI integration. This led to the first research question examining how faculty at this private university perceive AI's role in enhancing teaching methodologies.

RQ 2 Implementation Challenges:

While the literature documents general integration challenges, this study aimed to identify the barriers this private university encountered in integrating curriculum and teaching practices.

RQ 3 Administrative Transformation:

Building research about AI's administrative impact, the third question explored how AI has transformed administrative processes at this private university.

RQ 4 Future Vision:

Research indicates varying perspectives on AI's future in education. The fourth question examined how this private university's faculty envisions AI's future role in their fields.

RQ 5 Ethical Considerations:

Given the prominence of ethical concerns in current literature, the final research question investigated faculty concerns AI adoption within our institutional context. The literature review laid the theoretical framework for understanding the many-faceted effects of AI in higher learning education, which needs rigorous implementation tactics and careful ethical weightage (Murgia & Staton, 2023). This study's methodological framework and research goals were developed based on this analysis.

Method

The analysis of the use of AI technologies in learning environments demonstrated outstanding potential and significant challenges of AI adoption. Educators here faced a range of complexities while implementing these new tools in teaching-learning practices, especially regarding ethical uses, security precautions, and systemization approaches. This study explored these challenges by engaging educators' opinions on the application of AI within all stages of the instruction process and after instruction occurred. There was a focus on coding and extracting recurrent patterns, and adherence to intercoder solid reliability standards within educational research domains (Cardona et al., 2023). A department chair summarized their analysis of the findings as follows: "It became clear to participants that the use of AI cannot be a simple process of adding technological processes to the current practices since each of the phases requires addressing of ethic and learning and teaching issues" (Participant 2). As a research method, this approach gave detailed insights into educators' experiences in the technological modernization process and the ways it influenced education.

Research Questions

In the current investigation, the associations between population characteristics, intervention features, study comparators, and outcomes were analyzed using an evidence-based research question construction framework known as PICO (Population, Intervention, Comparator, Outcome) (Richardson et al., 1995). Within this systematic framework, five pivotal research questions were identified, which determined the focus of the

current study. The study focused on university faculty, examining their firsthand experiences and how they acknowledge AI Integration in various tasks. Another senior faculty member participant observed, "The questions we explored addressed all areas of our academic responsibilities: course development and delivery, assessment of students" (Participant 2).

The investigation examined faculty perceptions across multiple dimensions:

- Pedagogical adaptations in teaching methodologies
- Transitions in curriculum development processes
- Evolution of administrative responsibilities
- Integration of AI in research practices
- Applications within specific disciplinary contexts
- Ethical considerations and implementation challenges

As one faculty participant reflected, "These questions pushed us to examine not just how we used AI, but how it transformed our fundamental approach to education" (Participant 7). This comprehensive examination of faculty experiences provided insights into the multifaceted impact of AI integration across academic roles and responsibilities.

Data Collection

The study used semi-structured interviews (McIntosh & Morse, 2015) with the participants from this private university who had integrated AI technology into their daily teaching practices. Out of fifteen interested faculty members, eleven participants were selected for the study using survey questions to determine their levels of active practice in implementing AI. It also ensured that only rich and practical knowledge about integrating AI into scholastic domains was obtained.

The participant demographic profile revealed diverse representation across academic ranks and experience levels:

Experience Distribution:

- Mid-career faculty (11-15 years) represented the largest cohort (6 participants)
- Early-career (0-5 years) and senior faculty (21+ years) provided complementary perspectives.
- Age distribution concentrated in the 45-54 range (6 participants)

Departmental Representation:

- College of Business and Management (5 participants)
- College of Arts and Sciences (3 participants)
- College of Education (2 participants)
- College of Communication and Design (1 participant)

The participant selection process was an anonymous online survey with foundation questions to qualify potential subjects. This screening process allowed only faculty with appropriate experience in integrating AI to participate, leaving those without equivalent implementation experience aside. According to one participant, the selection process helped build a cohort from whom valuable insights into AI's application in education could be derived. The methodological approach allowed a variety of viewpoints yet enrolled experienced practitioners (Akgun & Greenhow, 2021). Please see Table 1.

Validity and Reliability of the Study

In this bibliometric analysis research, the literature review, identification, and selection of relevant studies, formulation of core problems related to the topic, examination of selected studies under consistent headings, synthesis, and reporting are presented in detail. The objectives of this research and the problems defined for this study are clearly and explicitly presented. Ensuring the validity of the examined and synthesized studies is crucial for reliability. Therefore, to minimize errors, the selected studies were exported and thoroughly reviewed over an extended period. Consultations were conducted with experts in the field, and a consensus was reached before analyzing the obtained information.

Table 1. Demographics of participants

Years in Higher Education	Frequency (Total)	College	Frequency (College)
0-5	1	College of Business and Management	5
6-10	2	College of Education	2
11-15	6	College of Arts and Sciences	3
16-20	1	College of Communication and Design	1
21-30	1		
Age Group	Frequency (Age)	Rank	Frequency (Rank)
35-44	3	Assistant Professor	5
45-54	6	Associate Professor	5
65-70	2	Adjunct Instructor	1
Years at University	Frequency (Years)	Highest Course Level Taught	Frequency (Level)
0-5	7	Undergraduate	6
6-10	1	Graduate	4
11-15	3	Doctoral	1
Gender	Frequency (Gender)		
Male	8		
Female	3		

Data Quantification Procedure

The research team undertook semi-structured interviews with 11 faculty members from the selected private university, utilizing a rigorous mixed-method analytic approach. Recordings of the interviews were transcribed verbatim and subjected to systematic thematic analysis through the NVivo 14 software. Findings from the literature review played a role in deriving inductively from the raw data collected and likewise applying it deductively during thematic analysis (Zamawe, 2015). One department chair reflected, "The analysis process revealed layers of meaning we hadn't anticipated in our initial discussions" (Participant 9).

The quantitative analysis revealed distinctive patterns in thematic frequency:

- Faculty references averaged 4.45 times per interview.
- Adaptation discussions demonstrated significant variance (SD = 0.60)
- Statistical validation through ANOVA showed comparable results between manual and auto-coding approaches ($F = 1.19$, $p = 0.28$)

The analysis identified an outlier through Tukey's method (1977), exceeding 1.5 times the interquartile range (IQR). One participant noted, "The transformation of our teaching methods went far deeper than we initially anticipated" (Participant 7). This observation aligned with the statistical findings showing faculty adaptation as a primary concern.

Integration of quantitative and qualitative findings revealed nuanced perspectives on AI implementation. While 60% of faculty expressed concerns about over-reliance on AI for personalization, they simultaneously acknowledged its potential benefits. "We sought balance between technological innovation and preserving essential human connections in education" (Participant 4).

The methodological framework acknowledged Maxwell's (2010) caution regarding numerical interpretation of qualitative data, maintaining contextual integrity throughout the analysis. This approach identified three distinct research tiers: primary focus areas, secondary interests, and emerging trends, ultimately informing 16 key themes for investigation.

Data Reliability and Validation

Specifically, the methodological approach was very systematic, where tasks such as the validity of measures involving the analysis of the data, which is often rich narrative, were given high priority. According to Syed and Nelson (2015), the research team devised extensive coding instructions that aligned both the process and

outcomes. Interviewer 8, a senior researcher, said, “Our validation process was growing with the processes as we faced specific narrative patterns in the faculty’s replies.”

The methodological framework incorporated multiple validation strategies:

Iterative Coding Process:

- Multiple rounds of thematic analysis
- Cross-validation among coding teams
- Regular reliability assessments
- Systematic documentation of coding evolution

Mixed-Methods Integration:

- Quantitative validation of qualitative patterns
- Statistical verification of coding reliability
- Triangulation of data sources
- Integration of multiple analytical perspectives

Quality Assurance Measures:

- Regular team calibration sessions
- Documented decision-making processes.
- Systematic review protocols
- Continuous reliability assessment

Along those lines, one of the coding team members commented: "Every cycle uncovered more layers of meaning; it was like doing microanalysis in a close-knit community where the layers of meaning had to be painstakingly worked on in order to refine the analysis" (Researcher B). The study remained distinctly close to the general guidelines for remaining flexible within the methodology for the study in line with the themes that surfaced.

Statistical validation included:

- Intercoder Reliability
- Thematic Saturation
- Cross-validation Information
- Calculation of Reliability Coefficient

Such a comprehensive approach ensured procedural transparency and analytic reproducibility according to current best practices in qualitative research methodology (Syed & Nelson, 2015). Consolidating various validation techniques enhances the study's findings while allowing for an inquiry to remain flexible.

Data Analysis

This present study has relied on a mixed method to study the design of artificial intelligence within learning spaces. Per the opinion of Noyes et al. (2019), the mixed method approach reflects the view that research on complex educational settings programs must be regularly conducted in a mixed setting. Also, Researcher B stated that pairing numerical patterns with narrative insights was illuminating in terms of dimensions of the faculty experience that needed to be addressed individually by each method. The analytical framework incorporated three primary components.

Quantitative Analysis:

- Statistical pattern identification
- Thematic frequency distribution
- Correlation analysis
- Outlier detection

Qualitative Assessment:

- Narrative theme exploration
- Contextual interpretation
- Faculty experience analysis
- Implementation pattern identification

Mixed-Methods Integration:

- Cross-validation of findings
- Contextual pattern analysis
- Thematic synthesis
- Comprehensive interpretation

There was also great concern about the statistical soundness of the findings all through the analysis stage. As suggested by Jones (2019), the research team exercised an extremely high level of outlier analysis to minimize data misinterpretation. Again, reflecting the idea that each statistical anomaly was an outlier, one faculty researcher stated, “Each participant stated that they actualized at least one perspective worthy of deeper

examination" (Researcher C). This allowed numerators to be determined while remaining as close as possible to real-life situations for faculty.

The methodological synthesis identified more complex AI implementation patterns and included both objective data about effectiveness and subjective opinions of faculties. This strengths-based, coaching-focused approach improved knowledge about the degree to which specific characteristics of learners and learning environments moderated the impact of the intervention.

Quantitative and Qualitative Analysis

The analysis utilized dual analytical strategies that enabled the comparison of the numbers as well as thematic analyses of the experiences of the faculty with the integration of AI. These complex interconnections were unveiled in a detailed manner through this analysis of the implemented practices and the teaching and learning processes. The analysis revealed prominent thematic patterns as also viewed in Figure 1.

Primary Themes:

1. Ethics and Responsibility:
    - Highest reference frequency
    - Present across all participant interviews
    - Notable outlier in statistical distribution
    - "The ethical dimensions of AI integration demanded constant attention" (Participant 4)

2. Faculty Adaptation:
    - Second most referenced theme
    - Strong correlation with implementation success
    - "Our teaching methods evolved significantly as we integrated AI tools" (Participant 7)

3. Skills and AI Literacy:
    - Consistent presence across interviews
    - Connected to student outcome measures
    - Emphasized practical implementation challenges

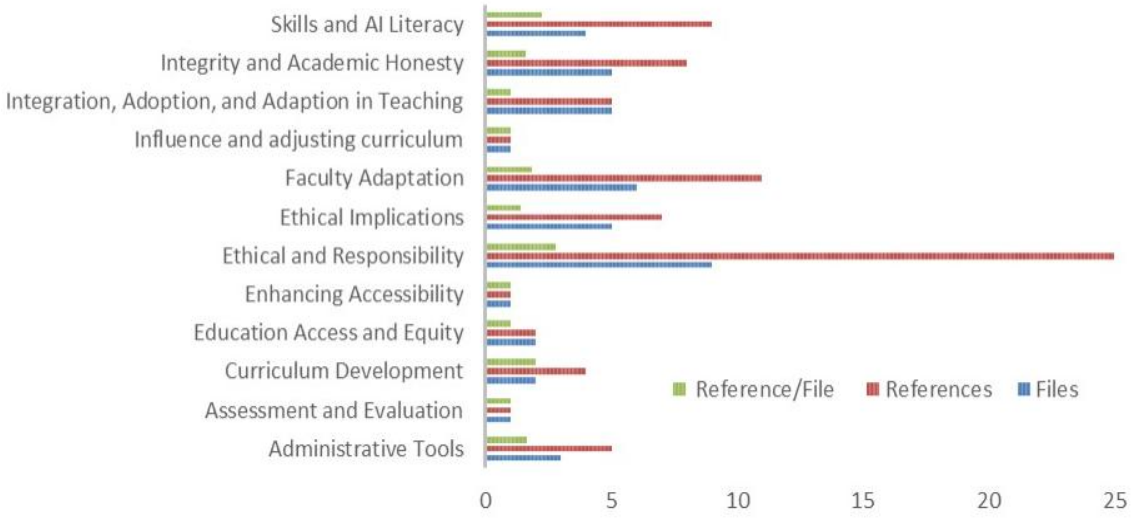

Figure 1. References, files, and relative reference per file

The relative reference analysis also showed the consistencies in the different files, while Ethics and Responsibility were bigger than the statistical average. This was consistent with faculty narratives regarding ethical concerns surrounding the use of AI. As one department chair mentioned, “There was an ethical consideration in every decision we made regarding AI” (Researcher B). The relative references per file gave equivalent results.

Outlier Analysis

Statistical examination of reference patterns revealed significant outliers through z-score analysis of references per file. The investigation identified ‘Ethics and Responsibility’ as a prominent statistical outlier (z-score = 2.09, $\alpha = 0.05$), warranting detailed contextual analysis. One senior faculty member reflected, “The ethical dimensions of AI integration consistently emerged as our primary consideration, beyond technical implementation concerns” (Participant 3). Notice that the theme on “Ethical and Responsibility” was found to be an outlier as viewed in Figure 2.

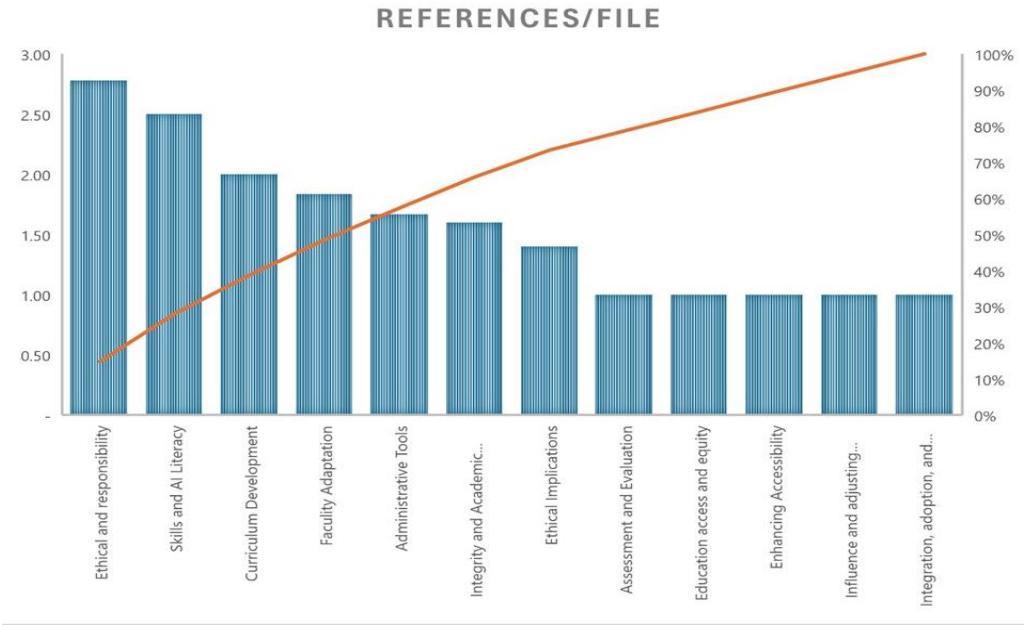

Figure 2. Pareto chart of themes

The analysis revealed several key patterns:

1. Statistical Significance:

- Ethics and Responsibility z-score: 2.09
- Significance threshold: $\alpha = 0.05$
- Standard deviation: 0.87
- Confidence interval: 95%

2. Contextual Implications:

- Primary ethical considerations
- Implementation impact assessment
- Faculty decision-making patterns
- Integration strategy development

3. Thematic Integration:

- Ethical framework development
- Technology implementation guidelines
- Faculty support mechanisms
- Student impact consideration

Ethics and responsibility emerged as statistical outliers and fundamental considerations in AI integration. “The ethical implications of AI adoption shaped every aspect of our implementation strategy,” noted one interviewee (Participant 6). This finding provided crucial insights into faculty approaches to AI integration, suggesting that ethical considerations were the primary drivers of implementation decisions.

Correlation and Regression Analysis

All the returns displayed significant correlations between the thematic references and file distributions at various analytical levels. This research compared the relationships between variables, with and without the outliers to allow for an all-encompassing view of the data. Key statistical findings emerged as depicted in Figure 3.

Thematic Correlations:

References-Files with ethics: $r = 0.92$ ($p < 0.001$)

References-Files without ethics: $r = 0.91$ ($p < 0.001$)

Regression strength (R^2): 0.85 (with ethics)

Adjusted R^2: 0.83 (without ethics)

Figure 3. Thematic References Distribution

Auto-coding Analysis:

- All codes correlation: 0.77
- Excluding "Faculty" correlation: 0.82
- R^2 with Faculty: 58% ($p < 0.001$)
- R^2 without Faculty: 67% ($p < 0.001$)

The strong correlation coefficients indicated robust thematic patterns across files. One researcher noted, “The statistical consistency reinforced our confidence in the thematic analysis framework” (Researcher A). The R^2 values demonstrated that file quantity explained substantial variance in thematic frequency, suggesting reliable coding patterns across data sources.

Detailed Analysis of the Dataset

Various aspects of implementation were hence delineated upon examining faculty engagement in adopting AI per different contexts in academia. The study identified 'faculty engagement' as the central theme across papers, giving rise to 49 references from 11 sources (mean = 4.45 references/source). Such frequency pattern emphasizes the role of the faculty in achieving success in AI implementation in higher educational contexts (Zawacki-Richter et al., 2019). Among the key emerging thematic patterns are:

Primary References:

- Faculty Member mentions: 36 references (3.27/source)
- Faculty Roles: 7 references (1.75/source)
- Faculty Perspectives: 3 references (1.00/source)
- Development and Impact: 1 reference each

Implementation Contexts:

- Individual adaptation strategies
- Institutional support frameworks
- Professional development needs
- Role evolution patterns

The analysis revealed nuanced experiences among the faculty in AI integration (Crompton & Burke, 2023). A participant in the study recounted, "Our roles have evolved past that of posing information across the lines of instructional boundaries and integrating AI tools" (Participant 5). The faculty responsibilities underwent significant transformation and varied reference patterns across sources (Seo et al., 2021). The research further identified other areas that required exploration, such as faculty development issues and impact evaluation. Expressions such as "faculty advisor" and "seasoned faculty" insinuated that diverse experience shaped the adaptive approach. An interviewee commented, "Experience levels significantly shaped even the individual approaches to AI integration" (Participant 8).

It is evident from the findings that AI integration on campuses is not restricted to changing roles, expectations, and professional development needs, but is a multidimensional process requiring practitioners to change their conceptualizations of these roles within the institutional context. The data further clarified that effective AI uptake rests on a faculty-level analysis married to system-level thinking.

Results

Analysis revealed compelling patterns of faculty approaches to AI implementation, highlighting ethical considerations within educational contexts as viewed in Figure 4. The research in question corroborated Adams et al.'s (2023) framework regarding AI ethics in education while shedding light on distinct institutional viewpoints concerning ethical implementation strategies. One senior faculty member reflected, "Ethical considerations permeated every level of our decision-making process" (Participant 3).

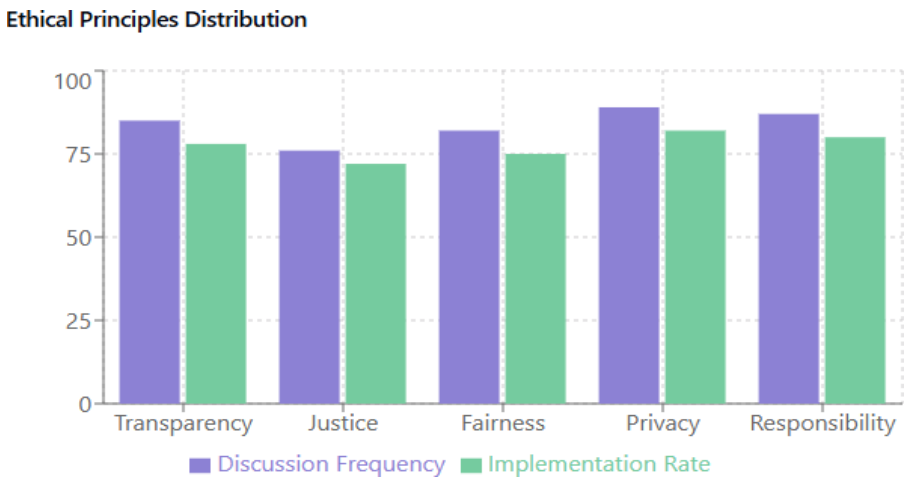

Figure 4. Ethical Principles Distribution

The outliers provided insights into ethical implementation patterns that were useful to the analysis. Following Yu and Yu's (2023) theoretical framework, the analysis employed multiple ethical perspectives.

Primary Ethical Dimensions:

- Transparency in AI implementation
- Justice in educational access
- Fairness in assessment
- Privacy protection
- Institutional responsibility

Implementation Frameworks:

- Deontological considerations
- Utilitarian approaches
- Virtue ethics applications

The investigation revealed a complex interplay between both ethical principles and practical strategies of implementation. One interviewee noted, "Balancing ethical requirements with educational effectiveness demanded careful consideration at every step" (Participant 7). This observation aligned with contemporary research emphasizing interpretability in AI decision-making processes (Yu & Yu, 2023).

Major Themes Identified

The analysis revealed distinct thematic patterns in faculty approaches to AI integration, with 'Ethical Considerations and Responsibility' emerging as the dominant theme (37% of coded segments). This finding aligned with Zhai et al. (2021) comprehensive review of 308 papers, which similarly identified privacy (42%), fairness (35%), and transparency (28%) as primary ethical concerns in AI-supported education.

Four primary themes emerged:

1. Ethical Considerations and Responsibility (37%):
   - Academic integrity concerns: "I've noticed that the classes where I do say you can use it for this project and this way is where I've run into a lot of trouble with students using it in all aspects" (Participant 9).
   - Critical evaluation emphasis: "One of the challenges is ensuring that the AI-generated content is fact-checked" (Participant 1).
   - Implementation guidelines: "I have taken on a role on the AI task force...it's just trying to figure out rules" (Participant 4).

2. Faculty Adaptation and Training (29%):
   - Pedagogical transformation: "Now everything's going out the window. So, it's caused me to completely rethink the way I teach" (Participant 4).
   - Assessment modifications: "Adapting to AI has required a complete overhaul of my approach to assignments" (Participant 2).
   - Professional development correlation ($r = 0.63$, $p < 0.01$)

3. Skills and AI Literacy:

- Workplace preparation: "We need to start to think about the way that they're going to use AI in their future jobs" (Participant 8).
- Critical thinking development
- Technical competency enhancement

4. Curriculum Development:

- Complex task design: "We need to push ourselves to come up with more complicated tasks for students" (Participant 8).
- Real-world application emphasis
- Creative problem-solving integration

The data indicated a highly significant correlation between the incorporation of AI training amongst the faculty and ethical frameworks, demonstrating the challenges of implementation can be best addressed through further professional development. Interviews with faculty pointed to the fact that there exists a need to harmonize technology with education practices and produce learners ready for a world in which AI will dominate in their careers.

Impact of Outliers on Analysis

There are some observations due to outlier detection, especially in what pertains to 'Ethical and Responsibility' themes, where researchers noticed patterns of what faculty is worried about in implementing AI. Using Tukey's (1977) procedure to identify outliers, these ethical references presented significant statistical differences (2.7 standard deviations above the mean). They heightened the importance of ethical issues regarding the integration of AI use for the faculty.

Key analytical patterns emerged:

1. Primary Outlier Impacts:

- Ethical references: 2.7σ above mean
- Data privacy concerns: 2.1σ above mean
- Implementation challenges: 1.8σ above mean

2. Sensitivity Analysis Results:

- Ethical theme persistence post-adjustment

- Thematic saturation confirmation
- Pattern reliability validation

The findings aligned with the global study of Holmes et al. (2022), which similarly identified ethical considerations as predominant among educators. Another interviewee reflected, " "The application of AI raised ethical questions on every decision point" (Participant 5).

Stood distinctively as the emerging themes through outlier analysis:

- Lack of skills to develop critical consciousness
- Cognitive influences
- Variations of applying strategy

These patterns substantiated the observations of Zhai et al. (2021) on AI impacts on cognitive development. One of the faculty participants remarked, "We had to think carefully about how AI tools might affect the development of our students' analytical skills" (Participant 3). The analysis showed that these contextualized approaches for implementation disprove the generic models of integrations in university settings.

Discussion

Through the juxtaposition of a vast amount of literature review with data gathered from the empirical context of this private university, intricate trends of AI adoption in higher education settings emerged. Whereas previous research focused on the benefits of the application of AI in teaching and learning, the views of the faculty revealed a more complicated picture of its practice.

Key findings emerged across multiple dimensions:

1. Ethical Framework Development:

- Guidelines for responsible implementation
- Privacy protection protocols
- Equity consideration mechanisms
- Transparency requirements

2. Support Systems for Faculty:

- Staff-training programs
- Implementation resources

- Professional development documentation
- Opportunities for collaborative learning

3. Implementation Strategies:

- Integrating technology in a balanced manner
- Retention of student engagement
- The adaptation of formative assessments
- Integrity of pedagogical practice

In addition to supporting the arguments, Nguyet et al. cited the effects of AI on education or aspects whereby AI was improvised or forbidden; the comments from one member of senior faculty interviewed in this study was, "The process of implementation showed me how much depending on technology has to do with consideration for ethical issues" (Participant 4).

The work builds on an ongoing debate about the ethics of introducing AI in higher education and identified central motifs:

- Deployment transparency
- Responsibility in use
- Equitable access
- P Respect of privacy

The findings supported Nguyen et al.'s call for cross-border ethical codes of conduct while graciously highlighting the practical hurdles that institutional practice will have to work through. The experience of the private university shows that the formation of a task force and triggering ideas have been important for new challenges caused by AI. Ethical issues pointed to the need for flexible practices for adaptive techniques in learning institutions.

Practical Implications

The study produced, therefore, commendable recommendations for educational stakeholders: a comprehensive approach in monitoring progress and observing due ethical considerations was warranted. The findings of this study are based on results backing Talwar's (2023) spotlight on faculty development and institution-specific means of putting it into practice.

Three key recommendations were offered:

1. Faculty team-based Development:

- Discipline-based training programs
- Hands-on AI tool experiences
- Continuous professional development and
- Technical literacy development---As noted by one participant, "Targeted training proved essential for successful AI integration across disciplines" (Participant 3).

2. Ethical Framework Development:

- Clear guidelines for implementation
- Regular reviews of the framework
- Building institutional networks; and
- Aligning with public policies and procedures---"Setting comprehensive ethical guidelines became foundational to our success of implementation" (Participant 7).

3. DG Integration Strategies:

- Enhancing quality education
- Improving admin efficiency
- Enhancing innovative teaching; and
- The universality of access.

Conclusion

The findings provided implementation strategies that are flexible enough to consider the needs of other disciplines in terms of how comfortable the faculty is. Calling for a certain level of global ethical consensus, Nguyen et al. (2022) identified the thematic areas:

- Providing transparency of implementation
- Appraisal of responsibilities for application
- Equitable access; and
- Incorporation of sustainable development.

It has been established in the research that administrative, and facilitator encounters experienced AI as a sweeping tool for transformations of quality assurance. One administrator pointed out that "AI transformation required equal reflections towards technological capabilities and education integrity" (Participant 5). So, too,

this would dwell on adaptive frameworks that demanded that which would afford varied responses to authorities as the embedded authority of AI in higher education.

Methodological Limitations and Constraints

The study revealed methodological constraints that should be regarded when interpreting the findings. The most significant limitation was that of a small sample size (n=11), with an institution-based focus at the university, thus hindering the generalizability of results to multiple educational contexts.

Another set of limitations arising from several areas include:

1. Sample Characteristics:
    - Small sample size (n=11)
    - Sole focus on a single institution
    - Context of a private university
    - Student population (~3,500)

2. Contextual Considerations Specific to the Institution:
    - Byte on private identity
    - Demography of a specific constitution
    - Variation of resource availability
    - Specificity of implementation approach

As Creswell and Creswell (2018) pointed out, although qualitative small-sample studies may offer rich data, broad generalizability to a more significant population still needs to be expanded. To quote one of the researchers, "Although we provided deep insights into our institutional context, wider applicability must be considered carefully" (Researcher A).

Other constraints include:

1. Disciplinary Distribution:
    - Overrepresentation in the STEM field
    - Bias toward early adopters (Zawacki-Richter et al., 2019)
    - Varied patterns of implementation
    - Discipline-specific challenges

2. Methodological Weaknesses:

- Restriction of data sources
- Limited presentation of triangulation
- Lack of classroom observation
- Voids of student perspectives

Tondeur et al. (2020) argue that institutional characteristics influence technological integration and suggest that one should interpret the findings in light of the context. Participant 8 remarked, "Our experiences may be quite dissimilar to those experiences at institutions founded on different resources and demographics."

Recommendation

The findings indicated potential areas for future studies to work on incorporating AI into postsecondary education settings. The findings also suggested several avenues for research further down the line, particularly concerning the longitudinal effectiveness of the study and its practical applications.

Several research opportunities emerged from multiple domains:

Longitudinal Studies Investigating the Impact:

- Sustained assessment of effectiveness
- Implementation practices transitioning over time
- Evaluation of effectiveness over longer durations
- Best practice identity: Long-term impacts remain critical to the effective integration of AI

The Development of an Ethical Framework:

- Implementation Guidelines
- Privacy protection protocols
- Bias mitigation strategies
- Transparency requirements- Crompton and Burke (2023) proposed that cooperating with researchers and policymakers is vital for developing guidelines covering the whole ballpark.

Enhancement of Accessibility:

- The investigation of the digital divide
- The establishment of inclusive practices
- Strategies for resource distribution

- Equity assurance initiatives

Faculty Development Research:

- Professional development optimization
- Support system effectiveness
- Integration methodology advancement
- Best practice identification

The findings emphasized alignment with SDG #4 objectives through:

- Quality education enhancement
- Personalized learning development
- Administrative efficiency improvement
- Inclusive practice promotion

Future research directions should prioritize 1) multi-institutional studies, 2) diverse methodological approaches, 3) longitudinal impact assessment, and 4) ethical implementation frameworks. As one researcher noted, "Future investigations must balance technological advancement with educational integrity" (Researcher A). This observation highlighted the necessity for comprehensive research addressing implementation effectiveness and ethical considerations in AI integration.

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Examining EFL Learners' Motivation in Vocabulary App Usage: The Moderating Role of Fundamental Drives

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Abstract

This study examines the relationship between vocabulary testing app usage frequency and motivation enhancement among adult EFL learners, with a focus on the moderating role of primal motivation (conceptualized as fundamental learning drives distinct from initial engagement factors). Analyzing data from 43 Chinese EFL learners, results revealed no direct correlation between usage frequency and motivation enhancement ($r = -0.069$, $p > 0.05$), challenging the assumption that increased app exposure inherently boosts motivation. However, primal motivation significantly moderated this relationship ($p = 0.002$), suggesting that learners with strong fundamental drives sustain engagement regardless of usage patterns. Additionally, English proficiency positively correlated with app usage ($r = 0.366$, $p = 0.016$), indicating advanced learners may utilize apps more strategically. The findings offer critical implications for theory and practice. Theoretically, they extend motivation frameworks to digital contexts by introducing primal motivation as a key sustainer of engagement, bridging gaps in MALL literature. Practically, they highlight the need for: (1) app developers to move beyond MCQ-dominated designs toward hybrid formats that stimulate deeper cognitive engagement; (2) educators to assess and nurture primal motivation (e.g., through goal-setting interventions) before app implementation; and (3) institutions to integrate apps as supplementary tools, particularly for proficient learners. This study calls for a paradigm shift in MALL design—from frequency-focused metrics to motivation-sustaining ecosystems—to optimize long-term language learning outcomes.

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Introduction

The rapid advancement of mobile-assisted language learning (MALL) technologies has revolutionized vocabulary acquisition, offering learners unprecedented access to learning materials and immediate feedback (Poláková & Klímová, 2020). Vocabulary testing applications like Wordela, Promova, and Baicizhan have become particularly prominent in global markets, with China's edtech sector showing especially high adoption rates (Mark, 2024). However, emerging research reveals a significant paradox: despite their technological sophistication and widespread use, these applications face substantial learner attrition, with 19-23% of adult users abandoning them within three months due to perceived assessment pressure and limited cognitive engagement (Ling et al., 2022; Metruk, 2022). This phenomenon mirrors challenges observed in English Medium Instruction (EMI) contexts, where research has demonstrated that students' English proficiency and motivational beliefs significantly influence their ability to process academic content deeply (Zhou, Fung, & Thomas, 2023; Fung & Macaro, 2021).

This study addresses this paradox by examining the relationship between vocabulary testing app usage patterns and sustained motivation among adult EFL learners, with particular focus on the moderating role of what is termed "primal motivation." This novel construct refers to the fundamental cognitive-affective drives that initiate and maintain learning behaviors in digital environments. While existing research has predominantly focused on initial engagement metrics, the current investigation probes the psychological mechanisms underlying long-term usage, especially in China's unique transnational education context where the majority of participants originate from Guangdong province. This focus is particularly relevant given that vocabulary acquisition, unlike many other language learning aspects, requires consistent, long-term practice to yield meaningful results (Zhang et al., 2023).

Understanding these dynamics carries both theoretical and practical significance. From a theoretical perspective, it bridges an important gap in knowledge, as traditional motivation frameworks (Dörnyei & Ushioda, 2021) and foundational works on learning persistence (Gardner et al., 1985) were developed before the digital learning revolution. The study builds on recent work by Fung and Lo (2023) on cognitive load in EMI contexts, extending these insights to the domain of vocabulary app design. Practically, the findings promise to inform the development of more effective learning technologies that can sustain engagement beyond the initial novelty period, addressing a critical challenge in the rapidly growing edtech sector.

The paper begins by reviewing relevant literature on vocabulary testing applications and motivation theories, establishing the theoretical foundation for the study. The concept of primal motivation is then introduced and operationalized, differentiating it from related constructs in the literature. The subsequent section presents a

mixed-methods study of 43 adult EFL learners, detailing the research design and analytical approach. Finally, the implications of the findings are discussed for both language learning theory and educational technology design, offering concrete recommendations for practitioners and developers working at the intersection of language pedagogy and digital learning innovations.

Literature Review

Vocabulary Testing Applications: Design and Limitations

Vocabulary testing applications are mobile-based tools designed to assess and enhance vocabulary knowledge through immediate feedback, predominantly using multiple-choice questions (MCQs) (Pasicolan et al., 2021). While MCQs offer efficiency in scoring and adaptability (Jones, 2021), their passive format often fails to promote deep cognitive engagement, leading to superficial learning (Jones, 2021). Research highlights a paradox: despite widespread adoption (e.g., Baicizhan's 67% penetration in China), attrition rates reach 19–23% due to assessment pressure and limited meaningful interaction (Ling et al., 2022; Metruk, 2022). This mirrors challenges observed in English Medium Instruction (EMI), where Zhou, Fung, and Thomas (2023) found that technological tools alone cannot sustain engagement without addressing learners' psychological needs. The reliance on MCQs underscores a critical gap in app design—prioritizing convenience over pedagogical depth.

Motivation in Language Learning: From Classrooms to Digital Contexts

Motivation, defined as the internal drive guiding goal-directed behaviors (Dörnyei & Ushioda, 2021), is pivotal for vocabulary acquisition. Traditional theories (e.g., Gardner et al., 1985) emphasize persistence in classroom settings, but their applicability to digital learning remains limited. For instance, Lee et al. (2022) demonstrated motivation's role in strategy use among Korean learners, while Fung and Macaro (2021) revealed that intrinsic motivation outweighs language proficiency in EMI contexts. However, current MALL research overly focuses on initial engagement metrics (Zhang et al., 2023), neglecting sustained usage drivers. This gap is critical, as vocabulary learning requires long-term practice (Zhang et al., 2023), and apps often fail to maintain user interest beyond novelty phases. The disconnect between traditional theories and digital realities calls for frameworks that address motivation's role in technology-mediated persistence.

Primal Motivation: Bridging Theory and Digital Practice

This study introduces primal motivation—a novel construct capturing the cognitive-affective mechanisms that sustain digital learning. Unlike initial motivation (Dörnyei & Ushioda, 2021), which focuses on temporary

engagement, primal motivation emphasizes enduring behavioral (e.g., voluntary reuse) and affective (e.g., resilience to gamification fatigue) traits. Empirical support comes from Zhang et al. (2023), who found 23% higher retention among learners exhibiting these traits, and Fung and Lo (2023), who linked motivation-sensitive designs to reduced cognitive load in EMI. These findings align with Zhou, Fung, and Thomas's (2023) argument that self-efficacy and intrinsic goals drive deep processing more than proficiency. Yet, no study has applied this insight to MALL, leaving a gap in understanding how primal motivation moderates app usage and outcomes. By integrating EMI research with MALL challenges, this study proposes a framework to optimize apps for sustained engagement, moving beyond MCQ-dominated designs to address learners' fundamental psychological drives.

Present Study

This research endeavors to investigate the association between the frequency of utilizing vocabulary testing applications and motivation enhancement in EFL adult learners. It also seeks to analyze how the primal motivation of students influences this connection. Consequently, the research questions are as follows:

1. Does vocabulary testing apps usage frequency significantly correlate with motivation enhancement among EFL adult learners?
2. How primal motivation moderates the correlation between the usage frequency and the motivation enhancement?

Methodology

Participants

A group of 43 adult EFL learners were selected for this study using the snowball sampling technique. The recruitment strategy focused on engaging individuals from Guangzhou's local social networks, colleagues, and online platforms through WeChat. All 43 chosen participants successfully participated in the study by submitting completed questionnaires, thereby generating a reliable dataset for quantitative analysis.

Ethical Considerations

Participants were informed about the research objectives and methodologies by reviewing the instructions provided at the beginning of the questionnaire to guarantee anonymity and voluntary engagement.

Data Collection Methods

Questionnaires were used for data collection in this study. The survey instrument was tailored based on the open questionnaire tool within the Wenjuanxing Mini-App and subsequently administered online via WeChat, following a pilot study. The survey consisted of 14 questions covering demographic information, English proficiency, app usage frequency, and motivational factors for learning. Data collection began in April 2024 in Chinese and was later translated into English for analysis. The accuracy of the translation was validated by proficient English reviewers at the TEM8 level to maintain fidelity with the original text.

Data Analysis

A sum of 43 valid questionnaires was collected, numbered, documented in Excel, and analyzed using SPSSPRO. The Cronbach's α coefficient of 0.711 (As seen in Table 1) indicates questionnaire exhibits a notable level of reliability which supports the suitability of the data for analysis.

Table 1. Cronbach's α coefficient

Cronbach's α coefficient	Normalized coefficient	Items	Samples
0.711	0.716	14	43

Next, a frequency analysis was conducted to assess demographic variables like gender, age, education, and place of origin, along with data on application tools usage, including names, frequency, perceptions on multiple choice questions, primary motivation, and reasons for discontinuation. The study involved 43 participants: 29 females (67%) and 14 males (33%), aged 20-35. Education varied: 26 (60%) had bachelor's degrees, 16 (37%) had master's degrees, and 1 (3%) had an undergraduate qualification. English proficiency levels included CET4 (35%), CET6 (47%), and TEM8 (18%). Participants used various vocabulary tools, with Baicizhan being the most popular (67%), followed by Momo (9%), Bubeidanci (7%), and Duolinguo (7%). Most were from Guangdong (83%), with a few from Hainan, Shanxi, Shaanxi, Jiangsu, and Chongqing.

Moreover, results from the frequency analysis showed that the apps had multiple-choice questions. 83% completed questions in 1-10 seconds, 10% in 20-30 seconds, and 7% over 30 seconds. 44% found the questions average in difficulty, 51% easy, and 4% somewhat challenging. Motivation enhancement had varying impacts: 40% slightly positive, 33% average, 11% quite useful, 9% indifferent, and 7% highly beneficial. App usage duration ranged from 2 months to over 2 years, with daily usage times of 10 minutes to 1 hour. The primal motivations to start app use were study-related (70%), followed by personal interest (13%), peer influence

(7%), and work-related needs (2%). Reasons for discontinuation included boredom (12%), memory usage (7%), time-consuming (1), and peer influence (1).

To investigate the correlation between the usage frequency of vocabulary testing apps, primary motivation, and motivation enhancement in adult EFL learners, and to explore potential correlations with other variables, the subsequent phase entailed abbreviating and converting the variables into ordinal, nominal, and interval scales, accordingly. The aforementioned variables were utilized in a statistical assessment based on the normal distribution model.

Table 2. Results from the test for normal distribution

Variables	Samples	Median	Mean	SD	Skewness	Kurtosis	S-W test	K-S test
Gender	43	1	1.326	0.474	0.772	-1.476	0.591(0.000***)	0.428(0.000***)
Age	43	1	1.442	0.502	0.243	-2.038	0.632(0.000***)	0.369(0.000***)
Diploma	43	2	2.349	0.529	0.145	-0.927	0.691(0.000***)	0.373(0.000***)
EP	43	2	1.837	0.721	0.257	-0.995	0.801(0.000***)	0.24(0.011**)
MCT	43	1	1.233	0.571	2.409	4.746	0.457(0.000***)	0.495(0.000***)
MCD	43	2	2.256	0.928	-0.171	-1.22	0.826(0.000***)	0.277(0.002***)
ME	43	3	2.674	1.04	0.574	0.018	0.888(0.001***)	0.23(0.018**)
UD	43	2	2.488	1.369	0.551	-0.92	0.864(0.000***)	0.221(0.025**)
UF	43	2	2.023	0.556	0.014	0.499	0.728(0.000***)	0.354(0.000***)
PM	43	2	2.233	1.02	1.625	2.35	0.672(0.000***)	0.427(0.000***)

Note: EP = English proficiency; MCT = times to do a multiple-choice question averagely; MCD= multiple-choice question's difficulty; ME = Motivation enhancement; UD = Duration of Applications Usage Time; UF = Usage frequency; PM = Primal motivation.

The dataset, comprising fewer than 5,000 participants, was subjected to the Shapiro-Wilk test, which yielded a P value of 0.000***. This statistically significant result led to the rejection of the null hypothesis, indicating that the data deviate from a normal distribution. As shown in Table 2, the Kurtosis values were all below 10, and the Skewness values were under 3. The histogram of the data exhibited a bell-shaped curve, with higher frequencies in the center and lower frequencies at the extremes. Although the data were not perfectly normally distributed, they closely approximated a normal distribution and could be treated as such for the purposes of further analysis (Zong et al., 2010). Subsequent analyses involved Pearson correlation and linear regression to investigate the relationships between variables.

Results

Q1. Does the usage frequency of vocabulary testing applications that feature multiple choice questions significantly correlate with motivation enhancement among EFL adult learners?

The Pearson analysis (Table 3) revealed that the impact of the frequency of usage of vocabulary testing applications on motivation enhancement among EFL adult learners was found to be not statistically significant ($r = -0.069$, $p > 0.05$).

Table 3. Pearson analysis of usage frequency and motivation enhancement

	UF	ME
UF	1(0.000***)	-0.069(0.660)
ME	-0.069(0.660)	1(0.000***)

Note: UF = Usage frequency; ME = Motivation enhancement.

Q2. Does the primal motivation moderate the correlation between the applications utilizing frequency and motivation enhancement among EFL adult learners?

As shown in Table 4, the importance of Model 1 and Model 2 was relatively minor, with Model 3 emerging as the primary model incorporating interaction elements on the basis of Model 2. The moderating effect can be assessed through an analysis of the variation in the significance level of the F-value between Model 2 and Model 3 (Wen et al., 2005). The outcomes displayed in the moderating effect analysis table indicate a significance P value of 0.002, with the interaction term in Model 3 demonstrating significance.

This indicates that the moderating factor of primal motivation plays a significant role in affecting the variables of usage frequency and motivation enhancement. Consequently, primal motivation acts as a moderator in the relationship between the frequency of application usage and motivation enhancement among adult EFL learners.

Table 4. Results of moderating effect analysis

	Model 1				Model 2				Model 3			
	Coefficient	SE	t	P	Coefficient	SE	t	P	Coefficient	SE	t	P
Const	2.935	0.611	4.802	0.000***	3.545	0.946	3.746	0.001***	-0.161	1.4	-0.115	0.909
UF	-0.129	0.292	-0.443	0.660	-0.261	0.332	-0.788	0.435	1.908	0.717	2.661	0.011**
ME					-0.153	0.181	-0.846	0.403	1.304	0.467	2.79	0.008***
PM									-0.925	0.278	-3.322	0.002***
R^2	0.005				0.022				0.238			
Adjusted R^2	-0.02				-0.027				0.179			
F	F(43, 1)=0.196, P=0.660				F(2, 40)=0.455, P=0.638				F(3, 39)=4.059, P=0.013**			
$\triangle R^2$	0.005				0.022				0.238			
$\triangle F$	$\triangle F(1, 43)=0.196$, P=0.660				$\triangle F(1, 40)=0.715$, P=0.495				$\triangle F(1, 39)=11.608$, **P=0.002***			
Dependent variable：ME												

Note: UF = Usage frequency; ME = Motivation enhancement; PM = Primal motivation; SE = Standard error

Discussion

The study's results reveal critical insights about vocabulary app usage and motivation in EFL learning, beginning with the lack of correlation between usage frequency and motivation enhancement ($r = -0.069$, $p > 0.05$). These finding challenges common assumptions that more exposure to vocabulary apps automatically leads to greater motivation, while aligning with Metruk's (2022) observations about assessment-related stress in MALL environments. In contrast to earlier techno-optimistic views of app-based learning, these results confirm Zhou, Fung, and Thomas's (2023) EMI research showing that technology alone cannot sustain engagement without addressing deeper motivational factors.

Beyond the frequency-motivation relationship, the significant correlation between English proficiency and app usage frequency (Table 5) provides further nuance ($r = 0.366$, $p = 0.016$). While this supports Lee et al.'s (2022) theory of strategic competence among proficient learners, it simultaneously modifies Gardner et al.'s (1985) classroom-based assertion that motivation outweighs proficiency.

Table 5. Pearson analysis of English proficiency and usage frequency

	EP	UF
EP	1(0.000***)	0.366(0.016**)
UF	0.366(0.016**)	1(0.000***)

Note: UF = Usage frequency; EP = English proficiency.

In particular, higher proficiency enables more strategic app use, as seen in TEM8-level participants who employed apps as supplements rather than primary tools, whereas lower-proficiency learners may need additional scaffolding not addressed in traditional theories.

Regarding app design features, participants' reports of MCQs as "mechanical" and "unstimulating" (with 83% completing questions in under 10 seconds) offer important insights. Although MCQs offer efficiency benefits, these findings validate Jones's (2021) critique of passive recognition tasks and extend Fung and Lo's (2023) cognitive load theory to MALL contexts. Rather than supporting Almufareh's (2021) gamification thesis, the 19% attrition rate due to boredom challenges Belardi et al.'s (2021) efficiency argument for MCQ formats.

Most significantly, the study demonstrates primal motivation's moderating role ($p = 0.002$), which extends Gardner et al.'s (1985) persistence model to digital learning. Through behavioral indicators like voluntary reuse (70% study-related usage) and affective markers like gamification fatigue tolerance, the results show how traditional persistence mechanisms adapt to technology-mediated contexts. Furthermore, the triadic interaction between proficiency, usage duration and motivation enhancement (Table 6) strengthens Zhou et al.'s (2023) findings about the complex interplay between cognitive and motivational factors ($P = 0.014$).

Table 6. Linear regression analysis results

Linear regression analysis results n=43									
	Non-standardized coefficient		Standardized coefficient	t	P	VIF	R^2	Adjusted R^2	F
	B	SE	Beta						
constant	1.55	0.465	-	3.334	0.002***	-			
EP	0.2	0.206	0.139	0.971	0.337	1.011	0.191	0.151	F=4.736 **P=0.014****
UD	0.304	0.109	0.4	2.8	0.008***	1.011			
Dependent variable：ME									

Note: EP = English proficiency; UD = Duration of Applications Usage Time; SE = Standard error.

In summary, these results both converge with and diverge from existing research. On one hand, they support Metruk (2022) on assessment stress and Zhang et al.'s (2023) findings about sustained usage gaps. On the other hand, they contrast with Almufareh (2021) by showing gamification's limitations while extending Fung and Macaro's (2021) work through demonstrating intrinsic drives' primacy. Despite limitations in sample size (N=43) and regional focus (83% Guangdong), the robust moderating effect of primal motivation ($\Delta R^2 = 0.238$) offers valuable theoretical and practical insights for optimizing vocabulary apps to support sustained, meaningful engagement.

Conclusion

This study addressed a critical gap in mobile-assisted language learning research by investigating how vocabulary app usage frequency, English proficiency, and primal motivation interact to influence learner engagement. While previous studies focused primarily on initial app engagement metrics, this research examined sustained motivation through a mixed-methods design with 43 Chinese EFL learners. The findings revealed that app usage frequency alone ($r = -0.069$, $p > 0.05$) does not enhance motivation without the moderating effect of primal motivation ($p = 0.002$), and that higher proficiency learners ($r = 0.366$, $p = 0.016$) use apps more strategically. These results challenge the assumption that technological exposure alone drives learning outcomes, highlighting instead the importance of psychological factors in digital language acquisition. However, the study's limited sample size (N=43) and regional focus (83% Guangdong participants) suggest caution in generalizing these findings.

Future research should expand on these insights through longitudinal studies across diverse populations to validate primal motivation's role in different cultural contexts. Experimental designs comparing various app interfaces could identify optimal formats for sustaining engagement, while larger-scale studies might explore how demographic factors interact with motivational drivers. Additionally, research could investigate specific pedagogical strategies for cultivating primal motivation in digital learning environments. By addressing these directions, subsequent studies can build a more comprehensive understanding of how to design technology-assisted language learning that effectively supports long-term motivation and achievement.

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Investigation of the Effect of Writing Activities for Learning Purposes on Metacognitive Awareness in the Context of Mathematics Course

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Abstract

In this study, the effect of writing for learning activities on metacognitive awareness was investigated in the context of mathematics course. The study group of this research, which was conducted with a pretest-posttest control group quasi-experimental design method, consisted of 39 students (4th grade) selected by convenience sampling method. Data were collected using the "Metacognitive Awareness Scale for Children (MCAS-C) A form and writing for learning activities. The data were analyzed using SPSS. 26 program. As a result of the study, it was determined that writing for learning activities positively affected the knowledge of cognition sub-dimension and total metacognitive awareness in mathematics lesson, although not significantly, but did not cause any effect on the organization of cognition sub-dimension. This result makes the study different in terms of the fact that no significant difference was obtained in metacognitive awareness and all its sub-dimensions. As a result of the comparison of the ÜBFÖ-A form scores between the groups, no significant difference was found in all sub-dimensions of metacognitive awareness and total metacognitive awareness between the pre-test and post-test scores of the groups.

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Introduction

Although learning manifests itself through behavioral change, it is actually a cognitive process. Indeed, cognitive theorists (Jean Piaget et al.) have tried to explain the relationship between learning and cognitive processes since the early 1900s. While cognitive theories define learning as the process of receiving, understanding and applying information, they also emphasized the role of concepts such as cognitive flexibility, learning styles and metacognitive awareness in these processes.

There are many ways of learning. Reading, listening, observing and writing are some of them. In order to understand what is read, listened to and observed, it is necessary to think. However, in order to write, that is, to express the thought in writing, it may be necessary to re-run cognitive processes such as revising and organizing, or to use them more intensively. According to Langer and Applebee (1987), writing enables knowledge or thought to be restructured and applied in different contexts. As a matter of fact, Klein and Boscolo (2016), in their study in which they identified the trends in research on writing for learning activities, stated that cognitive theory and social-cultural theory are the theoretical basis of writing for learning activities. This theoretical basis and the idea that writing requires more intensive cognitive processes led us to investigate the question “Can writing activities for learning purposes contribute to increasing metacognitive awareness?”.

Metacognitive Awareness

Metacognitive awareness, one of the important concepts emphasized by cognitive theories, is the ability of students to monitor, manage and organize their own learning processes (Flavell, 1976). In the definition made by Wengrowicz, et al. (2018), metacognitive awareness is defined as the ability to understand and monitor one's own cognitive processes. In the literature, metacognitive awareness is considered as individuals' knowing how to learn by developing a conscious understanding of what, how and when to do in learning processes (Alkan & Açıkyıldız, 2020; Kalemkuş, 2021). In other words, metacognitive awareness can be defined as the individual's awareness of himself/herself about how he/she performs effective and meaningful learning, shaping and evaluating the learning process. In this framework, metacognitive awareness is generally explained with cognitive knowledge and cognitive regulation components (Schraw & Moshman, 1995; Sümen & Çalışıcı, 2016; Wengrowicz et al., 2018). While cognitive knowledge includes individuals' knowledge of their own cognitive structure, learning strategies and when to use these strategies, cognitive regulation includes strategies on how to use this knowledge (Alkan & Açıkyıldız, 2020; Kurtuluş, 2017; Lai, 2011).

The learner's awareness of what he/she needs to learn starts with the identification of missing knowledge, gaps in what is already learned, or what is necessary among the masses of knowledge. How to learn the missing or

necessary knowledge may require a number of trials for the learner. As a result of these experiments, the learner can decide what, how and when to learn more effectively, meaningfully and permanently. Thus, the learner can get the highest efficiency by subjectivizing the learning process.As a matter of fact, an efficient learning process is something that students and their teachers also aim for.Therefore, developing students' metacognitive awareness can help them get high efficiency from the learning process. As a matter of fact, there are many studies supporting this in the literature (Sağırlı et al., 2020; Tok et al., 2010; Alkan & Açıkyıldız, 2020). The results of these studies reveal the importance of metacognitive awareness for learners. For this reason, how students' metacognitive awareness can be developed or which educational practices can contribute to the development of metacognitive awareness during the primary school period when basic knowledge is learned is considered a problem worthy of research and was examined in this study.

Writing for Learning

With Janet Emig's (1977) “Writing as a Mode of Learning”, the idea that writing can be used as a learning tool beyond its use as a communication tool has become widespread in the educational literature. Dahlstrand (2006) stated that writing is an important process to enhance student learning in discipline-specific contexts beyond communication skills. Writing for learning (WLL) is a teaching method in which internalization is ensured by rethinking the information (Kennedy, 1980), which includes thinking and interpretation skills (Yıldız, 2012), and which aims to increase the comprehension and retention of information (Hand & Prain, 1996). This method emphasizes that writing genres can be used for more permanent (Lefter, 2006) and in-depth (Martin, 2015) learning of the content.

The integration of writing into learning processes has been supported by many studies (Carter et al., 2007; Graham et al., 2020; Kayaalp et al., 2020; Kayaalp et al., 2021; Öztürk & Günel, 2015; Gubte et al. 2021) by emphasizing its effectiveness in promoting critical thinking and conceptual understanding. For example, Kayaalp, et al. (2020) stated that SCM activities encourage students to conduct research, recognize different ideas, use evidence, and make comprehensive evaluations, and that these activities have positive contributions to critical thinking skills and critical thinking skills. Öztürk and Günel (2015) argued that writing is an integral part of the construction of scientific knowledge and improves learning outcomes in educational settings. Similarly, Kayaalp et al. (2021) stated that CLT activities create conducive environments for meaningful interaction with content and allow learners to acquire and operationalize knowledge through their interactions with writing materials. This is in line with the findings of Bangert-Drowns et al.'s (2004) meta-analysis, which found that SLL activities significantly increased academic achievement in various courses.

For the effective implementation of SLM activities in classrooms, teachers need to follow certain design processes and clarify which writing activity should be used for what and how. In this context, Hand and Prain (2002) put forward one of the frequently used design frameworks for SLW activities in the literature. According to Hand and Prain (2002), this framework, which aims to help teachers plan SCM activities, provides guidance to practitioners by emphasizing that the purpose, genre, topic, reader/audience and text production method should be determined when planning activities.

Mathematics and Metacognitive Awareness

The relationship between metacognitive awareness and mathematics is one of the most important research topics in educational psychology. There is an increasing number of studies emphasizing the important role of metacognitive awareness in mathematical problem solving and mathematics achievement. In the study of Abdullah et al. (2017), it was determined that there was a significant difference between the metacognitive awareness of students with different performance levels in solving non-routine problems in favor of the groups with high problem solving skills and it was emphasized that metacognitive skills should be emphasized in the problem solving process. The study by Hidayat et al. (2018), which showed that metacognitive strategies positively affect students' mathematical modeling competence, also supports this finding. In a study conducted by Demirtaş (2023), it was found that metacognitive awareness of primary school students significantly predicted their mathematics achievement, and it was emphasized that improving this awareness can increase learning outcomes related to mathematics. In the study conducted by Cahayasti & Indrasari (2018), it was stated that the increase in primary school students' mathematics problem solving achievement scores was positively correlated with their metacognitive strategy scores. Hassan & Rahman (2017) also reported a positive relationship between mathematics achievement and metacognitive awareness. Similarly, Özsoy (2010) and Bulut (2021) showed that metacognitive awareness is an important predictor of mathematics achievement. These findings point to the necessity of practices aimed at increasing metacognitive awareness in mathematics teaching.

As a matter of fact, studies integrating metacognitive awareness training into mathematics teaching in terms of teaching practices have shown positive results. Deniz (2017) showed that modeling activities that promote metacognitive awareness improved the results of mathematics problem solving. Similarly, Young & Worrell (2018) showed that students who used metacognitive strategies during mathematics tasks achieved higher scores in mathematics problem solving. These findings emphasize the inclusion of metacognitive awareness instruction in mathematics curricula and classrooms to improve students' mathematics problem solving performance.

Metacognitive awareness also has an indirect effect on students' mathematics problem solving achievement through other variables. For example, Hassan and Rahman (2017) suggested that effective metacognitive strategies can reduce the negative effects of anxiety on mathematics performance and increase motivation. Lai et al. (2015) showed that students with high levels of mathematical metacognition are better equipped to tackle mathematical problems, especially in the context of mathematics anxiety. These findings suggest that developing metacognitive skills can act as a buffer against anxiety and enable students to approach mathematical problems with more confidence and competence. Setyawati and Indrasari (2018), in a study with primary school students, showed that there was a positive relationship between students' use of metacognitive strategies while solving mathematical problems and their beliefs about mathematics. Özcan and Gümüş (2019) stated that students with high metacognitive awareness have more positive attitudes towards mathematics, which increases their motivation and participation in mathematical tasks. This relationship suggests that developing metacognitive skills can improve attitudes towards mathematics and ultimately contribute to higher academic achievement. However, Sümen and Çalışıcı (2016) reported a moderate negative relationship between pre-service teachers' metacognitive awareness and mathematical literacy self-efficacy beliefs. This indicates that high metacognitive awareness, while beneficial, can also lead to increased self-doubt in some cases. This nuanced approach suggests that teachers should implement metacognitive awareness training in a way that does not undermine self-efficacy.

The research results, some of which are mentioned above, consistently support the idea that metacognitive awareness is an important predictor of mathematics achievement and emphasize its importance in mathematics teaching. Accordingly, teachers may consider incorporating practices that increase metacognitive awareness into their classrooms and creating a culture of metacognitive awareness while trying to improve students' mathematics achievement.

Writing for Mathematics and Learning

The implementation of writing for learning in mathematics classrooms can make significant contributions as in other fields. Campbell et al. (2022) argued that SLW activities are underutilized in mathematics and mathematics teacher education and stated that they support students and teachers in the use of these activities. Powell et al. (2021) also stated in their study that the majority of educators believed in the importance of mathematics writing, but less than half of the participants used mathematics-related writing activities in their classrooms.

In mathematics classrooms, SLM can include a variety of activities such as summarizing, explaining, defending ideas or creating a story (Graham et al., 2020). Kostos et al. (2010) stated that mathematics journals positively

affect students' mathematical thinking skills and mathematical vocabulary use and can be used as a communication tool between students and teachers and also as an assessment tool for teachers. In support of these results, Van Dayke et al. (2014) also reported that CLT activities enable pre-service teachers to understand how students think.In addition, in meta-analysis studies (Arsenault et al., 2024; Graham et al., 2020; Bangert-Drowns et al., 2004), which examined studies on the use of SLM activities in mathematics courses, it was stated that these activities had a significant effect size on students' mathematics learning outcomes.

The use of SLM activities in mathematics learning-teaching processes requires the blending of content-specific knowledge, domain-specific vocabulary, and written expression skills (Hughes et al., 2019). Britton et al. (1975) categorized mathematical writing into three groups: expressive writing, formal writing for communication purposes, and poetic writing. Expressive writing involves students making sense of a problem, situation, or their own ideas using words, numbers, or visuals. Formal writing for communicative purposes involves students describing, defining, informing, or explaining about a mathematics topic. Poetic writing, on the other hand, involves showing original problems, different solutions, ideas in writing, ensuring fluency and flexibility in thinking, and elaborating ideas. Although there are many activities related to these writing types in the literature, it has been observed that these activities are expressed under different titles. In this context, some writing for learning activities that can be used in mathematics lessons are given below (Durmuş, 2024).

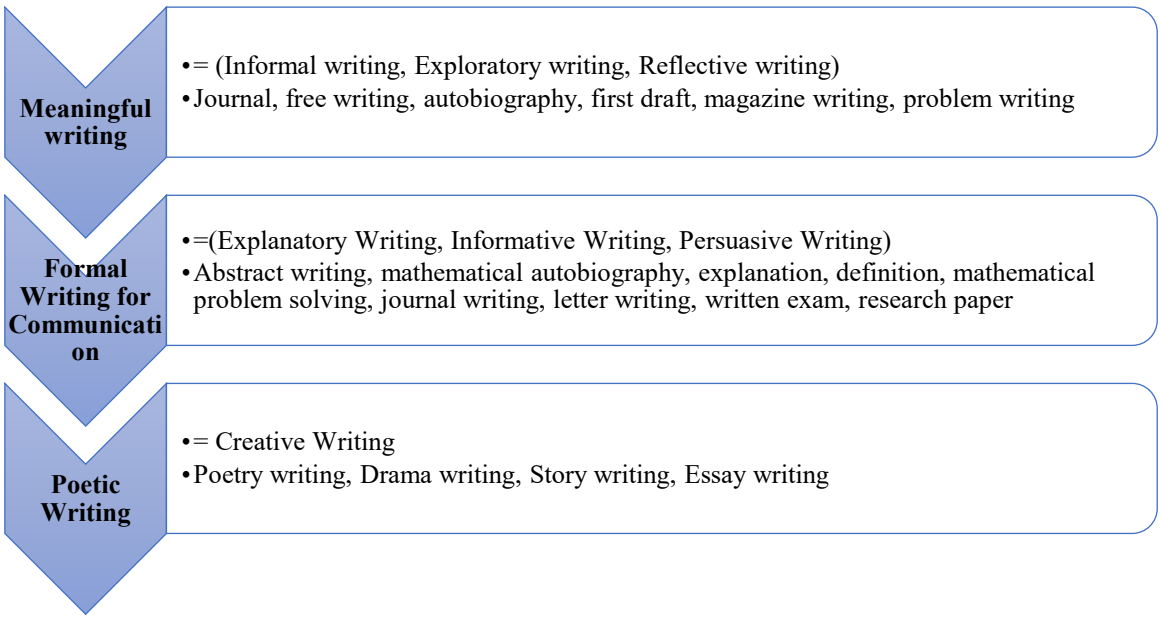

Figure 1. Writing Activities for Learning Purposes Used in Mathematics Lesson

In the study, the SCM activities of diary writing, letter writing, story writing and creating a class book were utilized. These activities were carried out with the students selected as the experimental group, and the effects

of these LWP activities on students' metacognitive strategies in the context of mathematics course were examined.

Writing Activities for Learning Purposes Used in the Study

Journal writing: Journal writing is one of the most effective learning tools used in mathematics teaching (Alro & Skovsmose, 2004). It is very effective in making sense of mathematics (Burchfield et al., 1993), in the realization of rethinking (Stan, 2012) and in explaining mathematical concepts (Kostos & Shin, 2010).

Letter Writing: Letter writing is an important learning tool that enables concepts to be structured in the mind (Yıldız & Büyükkasap, 2011). Knox (2017) stated that letter writing is an effective method that can be used in solving math problems. It is important that the letter writer is older than the addressee, that the subject matter is mastered before writing the letter, and that the letter is written by constantly reviewing the letter (Yıldız, 2014).

Story Writing: Story writing involves writing the events that take place in the form of experiences in the context of person, place and time (Takımcıgil-Özcan, 2014). The use of story writing in education has many benefits such as developing different perspectives (McEwan & Egan, 1995), providing problem solving opportunities (Jonassen & Hernandez-Serrano, 2002) and enabling the perception of new information.

Creating a Class Book: Creating a class book is one of the activities used by Wilcox & Monroe (2011) for SLM purposes. This activity consists of students writing on a determined topic, including symbols and figures in their writing, and after the writing is checked, the pages are merged.

Purpose of the Study

It is seen that most of the studies on metacognitive awareness (UA) in the literature (Aydın, 2022; Benli Özdemir & Arık, 2018) are aimed at measuring the level of metacognitive awareness of learners. However, these studies are far from answering the question of how metacognitive awareness can be developed. However, there are also studies (Altunkaya & Sülükçü, 2018; Bulut, 2021; Setyawati & Indrasar, 2018) that aim to determine the relationship between different variables and UA. In these studies, it was tried to explain the variables that metacognitive awareness is related to or predict metacognitive awareness. These studies are based on the perspective of determining the variables with which UA changes and expecting UA to change positively with these variables. The studies that seek to answer the question of how to increase the students' UFC are mostly experimental or quasi-experimental studies in which the variables affecting UFC are tested.In

this context, there are studies in the literature investigating the effect of metacognition-supported problem solving education (Arsuk, 2019), material development process (Sevim, 2014), flipped classroom model (Ertaş Karaaslan & Kaptan, 2023), case study method (Fırat Durdukoca, 2017) and many other variables on UIC. However, the abundance of variables that may affect UF makes it necessary to continue such studies with different variables. One of these variables is writing for learning activities. In this study, it was aimed to examine the effect of SLW activities on students' metacognitive awareness and its sub-dimensions. The research questions sought to be answered in this direction are as follows:

- Do the metacognitive awareness and sub-dimensions of the experimental group students differ significantly according to the pre-test - post-test data?
- Do the metacognitive awareness and sub-dimensions of the control group students differ significantly according to the pre-test - post-test data?
- Do metacognitive awareness and its sub-dimensions differ significantly according to the experimental group pre-test and control group pre-test data?
- Do the metacognitive awareness and its sub-dimensions differ significantly according to the post-test data of the experimental group and the post-test data of the control group?

Method

This study was conducted in a quasi-experimental design with a pre-test post-test matched control group, which is one of the quantitative research types. In this design, two of the groups ready to be matched are matched in the context of certain variables and as a result, they are randomly assigned to the treatment groups (Büyüköztürk et al., 2016). In this study, care was taken to determine the groups as equal to each other and it was examined whether there was a difference between the two groups determined in an unbiased manner in terms of dependent variables.

Working Group

The study group of research consists of 39 students, 20 of whom are in the experimental group and 19 of whom are in the control group, who are studying in the 4th grade of primary school in a village school in Pasinler district of Erzurum province. Convenience sampling method was used to determine the study group. Convenience sampling method is used for situations that are close and easy to access (Yıldırım & Şimşek, 2016). The reason for using convenience sampling method in the research is to determine the classes that will provide easy communication and to ensure that communication between the teachers and the researcher in the classes can be carried out effectively. In determining the experimental and control groups in the study, the

opinions of the school principals working in the district where the research will be conducted were taken and care was taken to ensure that the groups were equivalent in terms of achievement and attitude.

Data Collection Tools

The "Metacognitive Awareness Scale for Children Form A (MCAS-A)", which was used in the study to determine the effect of SCM activities on students' metacognitive awareness, was obtained from the literature (Karakelle & Saraç, 2007).

Metacognitive Awareness Scale for Children Form A (ÜBFÖ-Ç)

In the study, the "Metacognitive Awareness Scale for Children (MCAS-C) A form" developed by Sperling, Howard, Miller, and Murphy (2002) and translated and adapted into Turkish by Karakelle and Saraç (2007) was used to measure students' metacognitive awareness. The UBFC-Ç consists of two forms, form A and form B.Form A of the UBFC-Scale was developed for 3rd, 4th and 5th grade students, while Form B was developed for 6th, 7th, 8th and 9th grade students. Since the study was conducted with 4th grade students, Form A was used. Form A is a 5-point Likert-type scale consisting of two sub-dimensions, knowledge of cognition and organization of cognition, and a total of 12 items, all of which are positive. The highest score that can be obtained from Form A is 36 and the lowest score is 12. The validity and reliability of Form A was conducted with the data obtained from 565 students, 49.7% of whom were female and 50.3% of whom were male, studying in 3rd (n = 194), 4th (n = 183) and 5th (n = 188) grades. As a result of the factor analysis conducted to determine the construct validity of the scale, it was found that the factor loadings of the scale items ranged between 0.58 and 0.75, the KMO Kaiser-Meyer-Olkin (Sampling Adequacy Measure) value was 0.72, the internal consistency coefficient (Cronbach alpha) value calculated for the reliability study was α=0.76, and the test-retest correlation value was 0.64.The findings of the validity and reliability studies show that the scale has a valid and reliable structure.

Data Collection Process

The data collection process of the study was carried out in 22 weeks. In the first week of the study, the PPFC-A form was administered to the experimental and control groups as a pre-test; in the second and third weeks, the experimental group students and the experimental group teacher were informed about the SCM activities; in the fourth week, the implementation process was started and the activity implementations were finalized in the twenty-first week. Finally, the data collection process was completed in the twenty-second week of the study by applying the ÜBFÖ-A form to the experimental and control groups as a post-test.In the study, the pre-

test and post-tests were administered to the experimental and control groups at the same time.The tests were administered by the classroom teachers and the researcher managed the process by continuously controlling the classrooms during this process.

Application

The implementation of the SCM activities was carried out in two stages: “Preparation” and “Implementation Process”. Information on these phases is presented below.

Preparation Phase

The preparation phase of the study was carried out before the 2022-2023 academic year started. At this stage, IWL activities were determined, instructions to be considered during the implementation phase were determined, and IWL activity templates and sample IWL activities were prepared.

The studies in literature were taken into consideration in determining the IWL activities and attention was paid to determine the activities with previous examples of use. In this context, diary writing (Kostos & Shin, 2010), letter writing (Aktepe, 2020), story writing (Temizkan, 2011) and class book activity (Wilcox & Monroe, 2011) activities, which have examples of use in this context and were found to have an effect on achievement, were used in the study.

The guidelines suggested by Klishis (2003) were used to determine the guidelines to be considered in the implementation of the activities. In this context, the guidelines were formed by taking into account the suggestions that thoughts should be expressed, a specific interlocutor should be identified, the possibility that thoughts and spelling rules may be wrong should not be doubted, figures should be used, thoughts that are decided to be wrong should not be deleted but marked, and the activity should be finalized by repeated reading. The instructions were explained to the students before each activity.

IWL activity templates and sample IWL activities were prepared by taking into account the learning outcomes related to the implementation weeks. The content of the SCM activity templates was created by explaining the problem-solving process and expressing it with pictures and figures.

Implementation Phase

In the implementation process of the study, the SCM activities were introduced and implemented. In this context, students were informed about the SLM activities for 2 weeks before the implementation of the activities and the implementation of the activities was completed in 21 weeks. The implementations were carried out in 2-hour free activity lessons, one activity per week, after learning the mathematics outcomes related to the activities. The learning outcomes included in the activities were "addition, subtraction, multiplication and division with natural numbers". The importance of the use of SLM activities in the reinforcement phase in the literature (Bogad et al., 2007; Joyner & Muri, 2011; Martin, 2015) was effective in the implementation of the practices after the acquisitions were learned. While the IWL activities were applied to the experimental group students, no additional application was made to the control group students and the lessons in both groups were taught in accordance with the Ministry of National Education [MoNE] (2018) curriculum. During the implementation, care was taken to provide feedback to the students by the researcher. The implementation process was carried out by the class teacher of the experimental group and the researcher, and the researcher assumed the role of guiding the students throughout the implementation process. Information on the implementation process is given in Table 1.

Table 1. Information on the Implementation Process of the Research

	Journal writing				**Writing a letter**				**Writing a story**				**Creating a class book**			
Activity No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Planned Week	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Implementation Status	+	+	+	+	+	+	+	+	-	+	+	+	+	+	-	-
Implementation Week	4	5	6	7	8	9	10	11	13	14	15	16	17	18	20	21

As seen in Table 1, diary writing activities were used in the first 4 weeks of the implementation process of the research, letter writing activities were used in the second 4 weeks, and the activities were carried out in accordance with the determined plan. Story writing activities were used in the third 4-week period and class book creation activities were used in the fourth 4-week period.

Data Analysis

SPSS 26 package program was used for data analysis. In the study, the data were analyzed based on the findings obtained from the PPFAS-A form, and in this context, the effects of IWL activities on students' metacognitive awareness and its sub-dimensions were determined by t Test in Dependent Groups and t Test in Independent Groups. The significance level criterion was taken as 0.05 in all analysis procedures. The evaluation of the

ÜBFÖ-A form was carried out by defining the titles “Always”, “Sometimes”, and “Never” as 3, 2, and 1 points, respectively.

Firstly, in order to determine the type of analysis, it was checked whether the data were normally distributed and the homogeneity of variances. The normal distribution of the data related to the ÜBFÖ-A form was tested using the skewness and kurtosis coefficients (Field, 2009) and it was taken into consideration that these values were between -1.5 and +1.5 (Tabachnick & Fidell, 2013). The homogeneity of variances was checked by Levene's Test.

Validity and Reliability

In order to ensure internal validity within the scope of the research, it was ensured that the experimental and control groups were equivalent and that the validity and reliability of the data collection tools obtained from the literature were proven. The research plan was confirmed by the experimental group teacher and all of the data collected within the scope of the research were checked by the researcher and an academician.

In order to ensure external validity in the research, care was taken to select classes with sufficient number of students in the experimental and control groups, and the data collection, data analysis and implementation process of the research were explained in detail in the method section.

In order to ensure internal reliability in the study, the same curriculum was followed for both groups by paying attention to the similarity of the educational environments of the experimental and control groups.
The researcher was actively involved in the implementation process and guided the students in the creation of the activities.

In order to ensure external validity in the study, the synthesis of the data obtained was organized by the researcher and an academician.

Findings

In this section, the findings related to the metacognitive awareness of the students in the research sample are presented. In this context, the findings related to the question “Do SCM activities significantly affect students' metacognitive awareness and its sub-dimensions?” were expressed in 4 stages based on the research questions. The stages of expressing the findings are given in Figure 1.

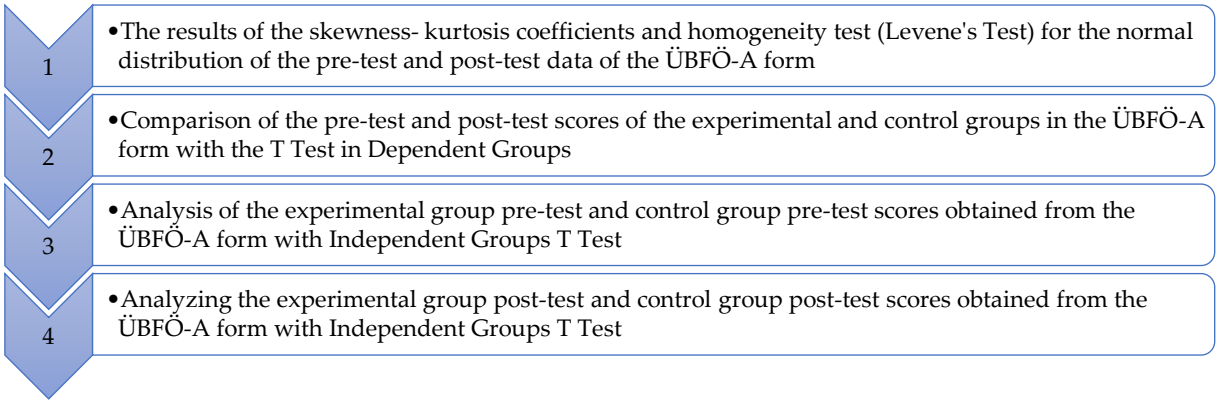

Figure 1. Stages of Expression of Research Findings

1-Specification of the skewness- kurtosis coefficients and Levene's Test results regarding the normal distribution of the pre-test and post-test data obtained from the ÜBFÖ-A form: Table 2 presents the skewness-skewness coefficients and Levene's Test results for the homogeneity of variances regarding the normal distribution of the pre-test and post-test data obtained from the ÜBFÖ-A form.

Table 2. Skewness-Skewness Coefficients and Levene's Test Results for the Pre-Test and Post-Test Data Obtained from the ÜBFÖ-A Form

	Test	Grup	Sd	Skewness	Kurtosis	Levene's	Sd1	Sd2	p
Cognition Knowledge	Pre test	Experiment	20	-.308	.730	6.819	1	37	.013
		Control	19	-.328	-1.332				
	Post test	Experiment	20	-.289	-1.119	2.218	1	37	.145
		Konrol	19	-.573	-.123				
Regulation of Cognition	Pre test	Experiment	20	-.575	-.459	7.815	1	37	.008
		Control	19	-.151	-.464				
	Post test	Experiment	20	-.016	-.528	.727	1	37	.399
		Konrol	19	.360	-.889				
Total	Pre test	Experiment	20	-.464	-.822	13.170	1	37	.001
		Control	19	.259	-.372				
	Post test	Experiment	20	.048	-1.228	3.457	1	37	.071
		Control	19	.167	-.348				

According to Table 2, in the context of examining whether the ÜBFÖ-A form scores are normally distributed between groups, it was seen that normal distribution was provided in total metacognitive awareness and all sub-dimensions between the scores of the experimental and control groups in the context of both pre-test and post-test. Similarly, in the context of examining whether the ÜBFÖ-A form scores were normally distributed

within the group, a normal distribution was provided in total metacognitive awareness and all sub-dimensions between the pre-test and post-test scores of the experimental and control groups.

According to the results of Levene's test related to the data of the ÜBFÖ-A form, a homogeneous distribution was not observed only in the pretest scores of total metacognitive awareness. It was determined that the variances had a homogeneous distribution in terms of posttest scores of total metacognitive awareness and pre-test and post-test scores of cognition knowledge and regulation of cognition sub-dimensions (Total-pre, p= .001, Total-post, p= .071; Cognition knowledge-pre, p= .013; Cognition knowledge-post, p= .145; Regulation of cognition-pre, p= .008; Regulation of cognition-post, p= .399; p> .05). In this context

2-Comparison of the pre-test and post-test scores of the experimental and control groups in the ÜBFÖ-A form using the T Test in Dependent Groups: The results of the comparison of the pre-test and post-test scores of the experimental group's ÜBFÖ-A form using the T Test in Dependent Groups are given in Table 3.

Table 3. Dependent Groups T Test Results for the Comparison of the Experimental Group's ÜBFÖ-A Form Pre-Test and Post-Test Scores

ÜBFÖ-A			**n**	**x̄**	**Ss**	**T**	**p**
Experiment	Cognition Knowledge	Pre test	20	11.70	2.77	-.849	.406
		Post test	20	12.05	2.23		
	Regulation of Cognition	Pre test	20	17.20	3.25	.000	1.000
		Post test	20	17.20	2.19		
	Total	Pre test	20	28.90	5.61	-.419	.680
		Post test	20	29.25	3.99		

As seen in Table 3, there was a difference of .35 points in favor of the posttest between the pretest and posttest mean scores of the experimental group in the knowledge of cognition sub-dimension ($\bar{X}$pre=11.70; $\bar{X}$post=12.05) and total metacognitive awareness ($\bar{X}$pre=28.90; $\bar{X}$post=29.25), while there was no difference in the organization of cognition sub-dimension ($\bar{X}$pre=17.20; $\bar{X}$post=17.20). As a result of the Dependent Groups T Test, which tested whether the determined differences were significant or not, no significant difference was found between the pretest and posttest mean scores in total metacognitive awareness and all sub-dimensions (ptotal=.680; pcognition= .406; p organization of cognition= 1.000, p<.05). This finding can be interpreted as that the SCM activities applied to the experimental group did not have a significant effect on metacognitive awareness and all its sub-dimensions.

The results of the comparison of the pre-test and post-test scores of the control group using the Dependent Groups T Test are given in Table 4.

Table 4. Dependent Groups T Test Results Regarding the Comparison of the Pre-Test and Post-Test Scores of the Control Group in the PPIPS-A Form

ÜBFÖ-A			n	x̄	Ss	T	p
Control	Cognition Knowledge	Pre test	19	11.15	1.89	-1.423	.172
		Post test	19	11.89	1.76		
	Regulation of Cognition	Pre test	19	16.21	1.75	-.836	.414
		Post test	19	16.57	1.67		
	Total	Pre test	19	27.36	2.79	-1.320	.203
		Post test	19	28.47	2.85		

As seen in Table 4, there was a difference between the pre-test and post-test mean scores of the experimental group in favor of the post-test in the knowledge of cognition sub-dimension (X̄pre=11.15; X̄post=11.89) by .74, in the organization of cognition sub-dimension (X̄pre=16.21; X̄post=16.57) by .36 and in total metacognitive awareness (X̄pre=27.36; X̄post=28.47) by 1.11 points. As a result of the Dependent Groups T Test, which tested whether the differences were significant or not, no significant difference was found between the pretest and posttest mean scores in total metacognitive awareness and all sub-dimensions (ptotal=.203; pcognition= .172; pregulation of cognition= .414, p<.05). This finding can be interpreted as that the methods in the current MEB mathematics program do not have a significant effect on metacognitive awareness and all its sub-dimensions.

3-The analysis of the experimental group pre-test and control group pre-test scores obtained from the UBFC-A form with Independent Groups T Test: The results of the Independent Groups T Test for analyzing the pre-test scores of the ÜBFÖ-A form in the context of the experiment and the group are given in Table 5.

Table 5. ÜBFÖ-A Form Pre-Test Independent Groups T Test Results

ÜBFÖ-A			n	x̄	Ss	T	p
Experiment	Cognition Knowledge	Experiment	20	11.70	2.77	-.709	.483
		Control	19	11.15	1.89		
	Regulation of Cognition	Experiment	20	17.20	3.25	-1.173	.248
		Control	19	16.21	1.75		
	Total	Experiment	20	28.90	5.61	-1.086	.287
		Control	19	27.36	2.79		

As seen in Table 5, there was a difference in favor of the pretest between the mean pretest scores of the experimental and control groups in the knowledge of cognition sub-dimension (X̄experiment=11.70 X̄control=11.15) .55, in the organization of cognition sub-dimension (X̄experiment=17.20; X̄control=16.21)

.99 and in total metacognitive awareness (X̄experiment=28.90; X̄control=27.36) 1.54 points. As a result of the Independent Groups T Test, which tested whether the determined differences were significant or not, no significant difference was found between the pretest mean scores of the experimental and control groups in total metacognitive awareness and all sub-dimensions (ptotal=.287; pcognition= .483; pcognitionregulation= .248, p<.05). In other words, the experimental and control groups were equivalent to each other in terms of metacognitive awareness before the SCM activity practices.

4- Analyzing the post-test scores of the experimental group and the control group obtained from the UBFC-A form with the Independent Groups T Test: The results of the Independent Groups T Test for analyzing the post-test scores of the ÜBFÖ-A form in the context of the experiment and the group are given in Table 6.

Table 6. Independent Groups T Test Results for the Post-Test of ÜBFÖ-A Form

ÜBFÖ-A			n	x̄	Ss	T	p
Experiment	Cognition Knowledge	Experiment	20	12.05	2.23	-.240	.812
		Control	20	11.89	1.76		
	Regulation of Cognition	Experiment	20	17.20	2.19	-.990	.329
		Control	20	16.57	1.67		
	Total	Experiment	20	29.25	3.99	-.694	.492
		Control	20	28.47	2.85		

As seen in Table 6, there was a difference between the posttest mean scores of the experimental and control groups in favor of the pre-test in the knowledge of cognition sub-dimension (X̄experiment=12.05; X̄control=11.89) .16, in the organization of cognition sub-dimension (X̄experiment=17.20; X̄control=16.57) .63 and in total metacognitive awareness (X̄experiment=29.25; X̄control=28.47) .78 points. As a result of the Independent Groups T Test, which tested whether the determined differences were significant or not, no significant difference was found between the pretest mean scores of the experimental and control groups in total metacognitive awareness and all sub-dimensions (ptotal=.492; pcognition= .812; p organization of cognition= .329, p<.05). Accordingly, the posttest mean scores of the experimental and control groups did not differ significantly in terms of metacognitive awareness after the implementation of SCM activities.

Discussion and Conclusion

According to the findings of the study, with regard to the scores of the ÜBFÖ-A form, which was applied to determine the effect of SCM activities on students' metacognitive awareness in the context of mathematics course; after the implementation process of the research was completed, a score increase was determined in the experimental group in favor of the posttest, although it was not significant in the knowledge of cognition

sub-dimension of metacognitive awareness and total metacognitive awareness. There was no score change in the organization of cognition sub-dimension of metacognitive awareness. This finding shows that CLT activities positively affected the knowledge of cognition sub-dimension and total metacognitive awareness in mathematics lesson, although not significantly, but did not cause any effect on the regulation of cognition sub-dimension. When the literature is examined, most of the studies (Balta, 2018; Bui & Kong, 2019; Chan & Aryadoust, 2023; Cho et al., 2010; Günel, 2009; Harten, 2014; Kaya & Ateş, 2016; Mansor et al, 2018; Negretti, 2012; Qin & Zhang, 2019; O "Neil, 2015; Robinson, 2007; Sato, 2022; Schakel, 2001; Shabaya, 2004; Steinbach, 2008; Strange, 2001; Sumarno, 2020; Xiao, 2016; Wang & Han, 2017; Whitebread et al., 2007; Wu et al., 2021), there is a significant and positive relationship between writing and metacognition. In this context, it has been stated that metacognition is an important factor affecting writing (Negretti, 2012; Pitenoee et al., 2017; Ruan, 2014; Stewart et al., 2015; Teng, 2016, 2019a, 2021; Teng & Yue, 2023) and that writing requires metacognitive skills (Bai et al., 2020; McCormick, 2003; Negretti & McGrath, 2018; Shub, 1998; Vincent et al., 2021). Writing has been characterized as a metacognitive practice process by some researchers (Grandy & Duschl, 2007; Hacker et al., 2009; Larkin, 2009; Teng et al., 2022).

In some studies, it has been concluded that writing performance is directly proportional to metacognitive skills (Djatmica et al., 2022; Farahian & Avarzamani, 2018; Qin & Zhang, 2019) and that students with advanced metacognitive skills have higher writing achievement (Conner, 2007; Eluemuno & Azuka-Obieke, 2013; Mansor et al, 2018; Negretti, 2012; Nelsi & Susana, 2008; Nguyen & Gu, 2013; Sumarno, 2020; Teng, 2016; Teng et al., 2022) and that metacognitive strategies are highly effective on writing performance (Graham, 2006; Teng & Zhang, 2021; Teng et al., 2022). This information shows that the activities of the SLM activities positively affect metacognition.

The positive effect of SCL activities on metacognition is supported by similar results in the mathematics course. For example, in Bicer et al.'s (2020) study examining the effect of SLM activities on mathematics achievement in the context of science, social and mathematics courses, it was found that SLM activities were effective on metacognition in relation to the success of solving mathematics problems; Craig's (2011) study examining the effect of expository writing on mathematics course found that expository writing was effective on metacognitive control in mathematics course; Özturan-Sağırlı (2010) examined the educational effects of writing activities in the context of students' views and found that writing activities were effective on the cognitive domain in mathematics and helped students understand better. Again, many studies in the literature (Gillespie et al. 2014; Powers et al. 2010; Santos & Semana, 2015; White, 2014) supported the results of this study and argued that writing positively affects metacognition in mathematics lessons. Similarly, Pugalee (2001) stated that writing improves metacognition in mathematics. In other words, in the context of the literature, it can be said that SLM activities positively affect metacognition in mathematics. In this study,

although it was determined that CLM activities positively affected the sub-dimension of knowledge of cognition and total metacognitive awareness in the context of mathematics course, the fact that there was no significant effect on metacognitive awareness and all its sub-dimensions makes the study different from other studies in the literature.

In the study, regarding the ÜBFÖ-A form scores of the control group students who did not receive any additional application after the application process, an increase in all sub-dimensions of metacognitive awareness and total metacognitive awareness was determined, although not significantly. In other words, the current teaching methods in the MoNE mathematics curriculum positively affected students' metacognitive awareness, although not significantly. In the study, it is noteworthy that the teaching methods in the current MoNE mathematics curriculum caused a positive, although not significant, effect on the regulation of cognition sub-dimension. This finding can be interpreted as that SLM activities have no effect on the sub-dimension of organizing cognition in mathematics course. When the literature is examined, it is stated that writing activities are very important on cognition (De Silva & Graham, 2015; Negretti & McGrath, 2018) and regulation of cognition (Bereiter & Scardamalia, 2009; Xiao, 2016) and that writing performance depends on the use of strategies related to cognition and regulation of cognition (Teng & Yue, 2023). In the studies of Ulu (2011) and Sumarno et al. (2021), it was determined that writing significantly affected the sub-dimensions of knowledge of cognition and organization of cognition. In some studies (Teng, 2016, 2019b), it was stated that especially the organization of cognition sub-dimension has a very effective role on writing. In this study, it is a difference for the literature that the SCM activities did not have an effect on the regulation of cognition sub-dimension of metacognitive awareness in mathematics. It can be said that this result is one of the rare results in the literature. In the literature, there are very few studies (Cheong, Zhu & Liu, 2022) in which writing activities similar to this research result did not have a significant effect on metacognition. It is thought that the effect that may cause this situation may be due to the fact that metacognition includes more than one strategy (Gammil, 2006).

As a result of the comparison of the pre-test and post-test scores of the PPFC-A form between the groups, no significant difference was found between the pre-test and post-test scores of the groups in all sub-dimensions of metacognitive awareness and total metacognitive awareness. In other words, the applied SCM activities did not significantly differentiate the post-test scores of the experimental group students in the mathematics course compared to the scores of the control group students without any additional application. In this context, it can be said that the SCM activities implemented in addition to the current MoNE program in mathematics course did not differentiate metacognitive awareness and all its sub-dimensions compared to the current teaching methods in the MoNE program.

Limitations

The research is limited to 39 students selected from a village school with a low socio-economic status, selected by convenience sampling method. In addition, since the research was conducted in a quasi-experimental design, the fact that the experimental and control groups did not consist of students selected from the ramdom can be considered as a limitation.

Recommendations

In the study, it was concluded that CLM activities positively affected the cognition sub-dimension and total metacognitive awareness in the context of mathematics course, although not significantly. In addition, it was seen that there are studies in the relevant literature indicating that SCM activities have significant contributions to metacognitive awareness in the context of mathematics lessons. Accordingly, teachers can be recommended to use SCM activities in mathematics lessons.

In the study, it was determined that the effect of CLM activities on metacognitive awareness in the context of mathematics lesson was not similar to the results of many studies in the literature. Accordingly, it can be suggested to examine the effect of CLM activities on metacognitive awareness in the context of mathematics lessons with other studies.

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Bibliometric Analysis of EEG and Eye Tracking Techniques in Executive Function Research

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Abstract

This study examines the relationship between vocabulary testing app usage frequency and motivation enhancement among adult EFL learners, with a focus on the moderating role of primal motivation (conceptualized as fundamental learning drives distinct from initial engagement factors). Analyzing data from 43 Chinese EFL learners, results revealed no direct correlation between usage frequency and motivation enhancement ($r = -0.069$, $p > 0.05$), challenging the assumption that increased app exposure inherently boosts motivation. However, primal motivation significantly moderated this relationship ($p = 0.002$), suggesting that learners with strong fundamental drives sustain engagement regardless of usage patterns. Additionally, English proficiency positively correlated with app usage ($r = 0.366$, $p = 0.016$), indicating advanced learners may utilize apps more strategically. The findings offer critical implications for theory and practice. Theoretically, they extend motivation frameworks to digital contexts by introducing primal motivation as a key sustainer of engagement, bridging gaps in MALL literature. Practically, they highlight the need for: (1) app developers to move beyond MCQ-dominated designs toward hybrid formats that stimulate deeper cognitive engagement; (2) educators to assess and nurture primal motivation (e.g., through goal-setting interventions) before app implementation; and (3) institutions to integrate apps as supplementary tools, particularly for proficient learners. This study calls for a paradigm shift in MALL design—from frequency-focused metrics to motivation-sustaining ecosystems—to optimize long-term language learning outcomes.

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Introduction

Executive function (EF) is a multifaceted construct that encompasses a variety of cognitive processes essential for goal-directed behavior, self-regulation, and adaptive functioning in daily life. In the context of neuroscience and neuropsychology, executive function is often associated with the activity of the prefrontal cortex and its connections with various brain regions, which together form the executive control network. This network is critical for high-level cognitive processes such as working memory, inhibitory control, cognitive flexibility, planning, and problem solving (Baggetta & Alexander, 2016; Shen et al., 2019; Diamond, 2013; Kolb & Neuwirth, 2020).

The conceptualization of executive function has evolved significantly over the years. Traditionally, executive functions were viewed as a single entity, but contemporary research suggests a more diverse understanding that separates “cool” and “hot” executive functions. “Cold” executive functions are primarily cognitive and involve processes such as working memory and attentional control, while ‘hot’ executive functions are more emotionally charged and relate to self-regulation in social contexts (Baggetta & Alexander, 2016; Siregar, 2018). This distinction is important as it highlights the different demands placed on executive functions in different situations, especially in educational and developmental settings (Blair, 2016).

Executive function (EF) studies have traditionally divided executive function into two main domains: cold EF and hot EF (Zelazo & Carlson, 2012). Cold EF includes purely cognitive processes, such as attention control, planning, and working memory, which usually do not involve emotions (Dixon, 2015). In contrast, hot EF relates to emotional or social situations, such as decision-making involving risk or emotion regulation (Martin & Delgado, 2011). EEG and ET technologies enable in-depth exploration of these two domains. EEG provides insight into brain activity patterns associated with cognitive control in cold EF and neural responses to emotional situations in hot EF (Guo et al., 2017).

ET, on the other hand, tracks visual patterns reflecting attentional priority in cold EF tasks and behavioral responses to emotional stimuli in hot EF (Both et al., 2011; Poyato & Vázquez, 2021). The integration of EEG and ET provides a holistic approach to uncover the relationship between neural and behavioral processes, which contributes to a better understanding of the complex mechanisms behind EF in various contexts. In real-life situations, 'cold' EF and 'hot' EF often work synergistically. For example, decision-making in situations involving risk or emotional distress requires a combination of cognitive control from 'cold' EF and emotion regulation from 'hot' EF (Roiser & Sahakian, 2013). Research suggests that this interaction is important in the context of education, mental health, and social skill development (Ono et al., 2011). The interaction between

'cold' EF and 'hot' EF not only influences individual decisions but can also shape group dynamics in complex social situations (Corr, 2013).

Neuroscientific studies have identified specific brain regions that contribute to executive function, particularly within the frontal lobes. The dorsolateral prefrontal cortex (DLPFC) is often involved in tasks that require cognitive control and decision-making, while the anterior cingulate cortex (ACC) plays a role in error detection and emotion regulation (Diamond, 2013; Kolb & Neuwirth, 2020). Moreover, the integration of information across different brain regions is essential for the effective functioning of executive processes, which suggests that executive functions are not only localized but also distributed across a network of interconnected areas (Kolb & Neuwirth, 2020; Alvarez & Emory, 2006).

Research has shown that executive functions are critical for academic success and social competence, especially in early childhood. The development of these functions is rapid during the preschool years and is influenced by both genetic and environmental factors, including parenting practices and educational interventions (Blair, 2016; Bernier et al., 2010). For example, children who exhibit strong executive function skills tend to perform better in math and literacy, suggesting that these cognitive abilities serve as foundational skills for learning (Clark et al., 2010; Rose et al., 2012). Moreover, the malleability of executive function implies that targeted interventions can improve these skills, leading to better outcomes across multiple domains (Blair, 2016).

In clinical settings, deficits in executive function are often observed in individuals with neurodevelopmental disorders, such as dyslexia and ADHD, as well as psychiatric conditions such as schizophrenia (Reiter et al., 2004; Sabhesan & Parthasarathy, 2005). These deficits can manifest as difficulties in planning, regulating and regulating emotions, which can significantly impact on daily functioning and quality of life. Therefore, neuropsychological assessments that evaluate executive function are essential for diagnosing and developing treatment plans for these individuals (Banich, 2009). The interaction between executive function and emotional processes is another important area of research. High levels of stress can impair executive function, highlighting the importance of emotional regulation in maintaining cognitive control (Blair, 2016; Finkenzeller, 2023).

This relationship underscores the need for a holistic approach in educational and therapeutic contexts, where cognitive and emotional skills are developed simultaneously to foster resilience and adaptability in children and adults (Fatwikiningsih, 2016; Warmansyah, 2023). In summary, executive function represents a complex interplay of cognitive processes that are critical for effective self-regulation and goal-directed behavior. Its development is influenced by a variety of factors, including brain structure, environmental context and emotion

regulation. Understanding the nuances of executive function through the lens of neuroscience and neuropsychology not only enhances our understanding of human cognition, but also informs practical applications in education, clinical practice and beyond.

Research on executive function (EF) is crucial in understanding human cognitive function as EF serves as a key regulator in various complex cognitive processes. EF includes abilities such as working memory, self-control, and cognitive flexibility, all of which are necessary for decision-making and adaptive behavior in everyday situations (Tsai et al., 2021; Logue & Gould, 2014). Research shows that EF is not only related to academic performance, but also to mental health and social skills (Yeh et al., 2016; Qi, 2023). In addition, studies on EFs provide insights into how impairments in these functions can affect individuals' quality of life, especially in more vulnerable populations such as the elderly and children with developmental disabilities (Corbo & Casagrande, 2021; Corbo & Casagrande, 2022). For example, research shows that educational interventions designed to improve EF can have a positive impact on children's cognitive development, indicating the potential to improve educational outcomes (Bermúdez-Rivera et al., 2022; Gentile et al., 2020). Furthermore, an understanding of EF also helps in the development of rehabilitation strategies for individuals with neurological disorders, such as dementia and bipolar disorder, where EF is often affected (Paunescu & Miclutia, 2015; Funahashi & Andreau, 2013). Thus, research on EF not only enriches our knowledge of cognitive mechanisms but also has significant practical implications in education and mental health.

The role of modern technology in measuring executive function (EF) is increasingly important, particularly through the use of techniques such as electroencephalography (EEG) and eye trackers (ET). EEG allows researchers to monitor the brain's electrical activity in real-time, providing insight into the cognitive processes underlying executive function, such as attention control and decision-making (Diamond, 2013; Friedman & Miyake, 2017). Using EEG, researchers can identify brainwave patterns associated with different aspects of EF, including inhibition and working memory, which are crucial in understanding how individuals function in everyday situations (Diamond, 2013; Friedman & Miyake, 2017).

Meanwhile, eye tracker technology provides valuable data on attention and visual information processing, which are key components in executive function. By tracking eye movements, researchers can evaluate how individuals prioritize information and make decisions, as well as identify difficulties in impulse control and attention (Willoughby et al., 2011; Zartman et al., 2013). The combination of these two technologies not only improves our understanding of EF but also enables the development of more effective interventions to improve cognitive abilities, especially in at-risk populations, such as children and individuals with neuropsychological disorders (García et al., 2021). Thus, modern technologies such as EEG and eye trackers contribute

significantly to the measurement and understanding of executive function, paving the way for more in-depth research and better clinical applications.

Executive function (EF) has significant relevance in various fields, including education, psychology, and neuroscience. In the context of education, EF plays an important role in facilitating learning and the development of academic skills. Research shows that good EF abilities, such as working memory and self-control, are positively associated with students' academic performance Ramírez-Luzuriaga et al., 2021; Diamond & Ling, 2016). For example, interventions designed to improve EF in children can improve educational outcomes and prepare them for greater academic challenges (Diamond & Ling, 2016). In the field of psychology, EF is closely related to mental health and psychological well-being. Deficits in EF have been associated with various psychological disorders, including depression and anxiety, suggesting that the ability to regulate emotions and behaviors is essential for good mental health (Farruggia et al., 2020; Rock et al., 2013).

Research has also shown that individuals with better EF abilities tend to have a higher quality of life and better adaptability to stress (Díaz-Morales & Escribano, 2014). From a neuroscience perspective, EF is considered an important indicator of higher cognitive function and is related to activity in the prefrontal cortex area. Neuroimaging research has shown that disruptions in brain networks that support EF can contribute to a variety of neurological and psychological disorders (Farruggia et al., 2020; Larsen et al., 2015). As such, a better understanding of EF may aid in the development of more effective intervention strategies to improve cognitive function and mental health (Kruger, 2011).

Electroencephalography (EEG) is a technique used to record the brain's electrical activity through electrodes placed on the scalp. The working principle of EEG is based on the detection of electrical signals generated by neurons as they communicate with each other. When neurons are activated, they produce changes in electrical charge that can be measured and recorded as brain waves Rini (2015). EEG provides information on a variety of mental states, including attention, emotions, and level of consciousness, with very high temporal resolution, enabling real-time detection of brain activity (Sahroni et al., 2020). The ability of EEG to detect brain activity in real-time makes it an invaluable tool in a variety of applications, including cognitive research, clinical diagnosis, and Brain Computer Interface (BCI) development (Nasution, 2023). For example, EEG can be used to monitor the brain's response to certain stimuli, such as in studies on the effects of stress or emotions, as well as to identify brainwave patterns associated with neurological conditions such as epilepsy (Sahroni et al., 2020). Thus, EEG serves not only as a diagnostic tool, but also as a means to understand more about human cognitive function and behavior.

Eye trackers are technologies used to record and analyze eye movements, which provide insights into visual attention and decision-making. The working principle of eye trackers involves using cameras and sensors to detect eye position and movement, including saccades (rapid movements between focal points) and fixations (periods where the eyes remain on one point) (Ayiei, 2020; Katz et al., 2018). Data obtained from eye trackers can be used to determine areas of interest (AOI) and analyze how individuals focus their attention on specific visual stimuli (Maruta et al., 2012).

The main function of eye trackers in monitoring visual attention is their ability to provide accurate data on where and for how long a person looks at certain objects or information. This is extremely useful in a variety of applications, including psychology research, marketing, and user interface design (Vervoort et al., 2013; Mera & Stumpf, 2014). For example, in the context of marketing, eye trackers can be used to understand how consumers pay attention to advertisements and products, as well as to identify the elements that attract their attention the most (Yu & Smith, 2016). Moreover, in the context of decision-making, eye trackers can help uncover the cognitive processes underlying individual choices, providing insights into how visual attention influences decisions (Shiro et al., 2021; Damji et al., 2018).

EEG and Eye Tracker technologies present distinct and unparalleled advantages when juxtaposed with conventional methodologies, which include but are not limited to interviews or self-report-based assessments that rely heavily on individuals' subjective accounts (Cantoni & Porta, 2014; Cott & Brenner, 1998). EEG, or electroencephalography, is able to capture and record the brain's intricate neural responses in real-time, providing direct insights into cognitive processes (Mustafa & Magnor, 2014; Millett et al., 2015), while ET, or eye tracking, closely monitors and analyzes visual patterns to elucidate the attentional priorities that individuals exhibit (Melman & Eden, 2016; Navalpakkam & Churchill, 2014). The remarkable synergy and integration of these dual advanced technologies facilitates comprehensive and multidimensional analyses that transcend the limitations and shortcomings of traditional methods, making it extremely difficult, if not impossible, to achieve the same level of understanding and insight through alternative approaches.

Previous studies on the integration of EEG and eye trackers in the measurement of executive functions have shown several limitations. One of the main challenges is that eye movements can often cause artifacts that interfere with the quality of EEG data, thus complicating accurate analysis Wenzel et al. (2016; Plöchl et al., 2012). Although there have been advances in eye tracker technology that allow recording of eye movements without interfering with EEG recordings, there is still a need for further research that combines these two methods effectively (Dimigen et al., 2011; Nikolaev et al., 2016). Existing research tends to focus on one method alone, thus overlooking the synergistic potential of combining both techniques to gain a more

comprehensive understanding of the cognitive processes underlying executive function (Scharinger et al., 2015; Luan & Lv, 2023).

In addition, the lack of bibliometric studies that map research trends and patterns in this area is also an obstacle. While some studies have used bibliometric approaches to evaluate trends in eye tracker research in general (Atabay & Güzeller, 2021; Yang & Wang, 2015), no analysis has specifically highlighted the integration of EEG and eye trackers in the context of executive function. This suggests an opportunity to conduct a more in-depth analysis of research developments in this area, as well as to identify areas that require further attention (Huang et al., 2020). As such, further research integrating these two techniques and a comprehensive bibliometric analysis may provide better insights into the dynamics and progress in executive function studies.

The integration of Electroencephalography (EEG) and Eye-Tracking (ET) technologies offers unique advantages in the study of executive function (EF) that other methods lack. EEG allows direct observation of brain electrical activity with high temporal resolution, providing real-time data on neural responses to cognitive tasks (Gevins et al., 1995). Meanwhile, ET complements the analysis by monitoring visual and attentional patterns, directly reflecting decision-making processes and attentional control (Eimer, 2015; Enstrom & Rouse, 1977). The combination of these two technologies provides a multidimensional approach that integrates brain and behavioral data, allowing for more in-depth analysis than traditional methods such as cognitive tests or self-report-based interviews. Moreover, the integration of EEG and ET is able to reveal the dynamic relationship between brain activity and visual behavior simultaneously, providing a more holistic insight into EF mechanisms, which was previously difficult to achieve with a single tool.

Bibliometric analysis is an important approach in academic research that aims to map research trends, identify collaboration patterns, and evaluate the contributions of institutions, countries, and authors in a particular field (Salinas-Ríos & García López, 2022; Dulla et al., 2021). In the context of executive function (EF) research, bibliometric analysis provides deep insights into the distribution of literature, emerging topics, and interrelationships between studies from various disciplines (Shekarro et al., 2021; Lyer & Srinivasan, 2020). Bibliometric analysis not only helps understand the dynamics of research development, but also plays a strategic role in fostering innovation, cross-national collaboration, and integration of interdisciplinary approaches (Sillet, 2013; Salinas-Ríos & García López, 2022). By utilizing bibliometric analysis, researchers can identify gaps in the literature and accelerate the development of new methods relevant for EF studies, especially with the integration of EEG and ET technologies. The use of this method also allows researchers to formulate more precise and relevant research questions, which can lead to findings that have a significant impact in the field of cognitive neuroscience.

Research in the field of executive function (EF) shows an increasingly broad pattern of collaboration, involving various institutions, countries and disciplines (Burgess, 1997; Ardila, 2019). Bibliometric analysis reveals close links between researchers from different regions, creating a global academic network that drives the development of EEG and ET technologies (Stefanidis et al., 2018). In addition, emerging research topics include the utilization of EEG to understand brain mechanisms in decision-making and attention, as well as the use of ET to explore visual patterns in educational and marketing contexts (Vecchiato et al., 2011; Tekin et al., 2017). Another trend involves the integration of advanced technologies, such as machine learning, to analyze complex EEG and Eye tracker data, further expanding the scope of applications in various fields (Jamal et al., 2023). This research highlights the importance of cross-institutional collaboration in driving technological innovation and deeper interdisciplinary development.

Results derived from comprehensive research on executive function, commonly referred to as Executive Function, have a wide range of practical applications that can be used in a variety of fields and contexts (Nemeth & Chustz, 2020; Pineda, 2000). For example, interventions based on EEG, which stands for electroencephalography, and ET, which signifies eye tracking, have been effectively used to determine and identify specific cognitive weaknesses or deficits present in children diagnosed with Attention Deficit Hyperactivity Disorder, or ADHD, and these identified weaknesses then lay the foundation for the development and design of specialized training programs that focus primarily on improving attention-related skills (Heywood & Beale, 2003; Kirk et al., 2017; Bikic et al., 2015). In the field of education, data collected regarding executive function is used strategically to formulate and create curricula designed to simultaneously foster the development of cognitive abilities and emotional skills ensuring a holistic approach to student learning and growth. (Romero López et al., 2017).

The purpose of this article is to conduct a bibliographic analysis related to electroencephalography (EEG) and eye tracking techniques in executive function research. The main focus of this analysis was to identify the most influential authors, map the most productive collaborations between researchers, institutions, and countries, and explore trends, developments, key contributions, and key concepts in the field. This review provides a comprehensive overview of the evolution of the literature in the field of executive function through a bibliographic approach, specifically through EEG and ET approaches. The contributions of this article provide significant academic implications in the field of neuropsychology, particularly in the use of EEG and ET to understand executive function performance. More than simply mapping research trends and patterns, this article identifies key factors that influence the relevance and acceptance of research in an academic context. By highlighting the importance of the literature as a foundation for the development of innovative ideas, both in theoretical frameworks and practical applications, this article reinforces the role of EEG and ET as important tools in exploring cognitive mechanisms.

It is hoped that the results of this study also emphasize how academic productivity can be enhanced through effective management of collaborative environments, creating synergies across disciplines to produce more valuable research. As such, this article opens up opportunities for broader academic collaboration, supports the integration of concepts from different disciplines, and provides a strategic foothold for more purposeful research in the future. This approach not only contributes to theory development in neuropsychology, but also to practical applications that can improve understanding and interventions related to executive function.

Method

Using bibliometric analysis serves as an important tool for understanding research trends, impact, and collaborations in various fields. These analyses quantitatively assess scientific output, enabling the identification of influential publications and emerging areas of research. For example, studies have shown that bibliometric methods can effectively track the progress and orientation of research in specific domains, such as fitness and music therapy applications, highlighting the importance of these analyses in guiding future investigations (Liu & Avello, 2021; Li et al., 2021). Moreover, bibliometric practices are increasingly being integrated into academic libraries, thus enhancing their ability to support researchers by providing insights into publication patterns and citation metrics (Gumpenberger et al., 2012). In addition, bibliometric studies have been instrumental in evaluating the impact of certain research initiatives, such as the NIH Clinical and Translational Science Awards, by demonstrating the value of interdisciplinary collaboration and resource allocation (Llewellyn et al., 2019). The application of bibliometric techniques not only helps in understanding the historical development of a research field, but also assists in forecasting future trends, thus making it an essential component in contemporary academic research (Hakimova et al., 2020; Liu, 2023).

This article was prepared by conducting a structured and systematic literature search, and it follows an existing protocol to obtain accurate and relevant results. The protocol contains more specific keyword definitions, time series filtering, and classification by grouping documents that are relevant to the general research topic. This approach aims to help access a variety of useful information including the nationality of the author, the field of research, the type of publication used, keywords and subject names related to the main theme. There is a procedure to be followed for the collection of data and information relevant to this issue.

Each step in the steps of the literature search was undertaken with care and attention to try to cover a wider range of data. In this article, as far as possible to support functional arguments, deep logical reasoning, and a balanced perspective. Data collection was conducted with a literature search on November 3, 2024 using the Scopus database from Scimago Research Group, Web of Science (WOS) from Clarivate Analytics and PubMed

from the National Library of Medicine. This process, using search criteria, keywords such as electroencephalography or eeg, eye tracker or or eye tracking and executive function or cognitive performance, time period (1992-2024), as well as document type (research article, conference paper, conference review, proceedings paper, review and early access).

Based on the overall search results in the data base, it produces 309 documents, including 178 documents from Scopus, 96 documents from WOS and 35 documents from PubMed. Furthermore, the results of the three databases were filtered, where 97 documents were identified as duplicates and 212 documents remained. The total remaining documents consisted of 157 articles, 11 conference papers, 6 conference reviews, 14 proceedings papers and 23 reviews and 1 early access review). This research adopted the bibliometric analysis method following two main stages as outlined by Župič & Čater (2014): first, study design and document collection; second, data analysis, visualization and interpretation. The analysis process was conducted using R Studio software version 2023.09.0, utilizing the Bibliometrics package and Biblioshiny package to support comprehensive data processing and presentation.

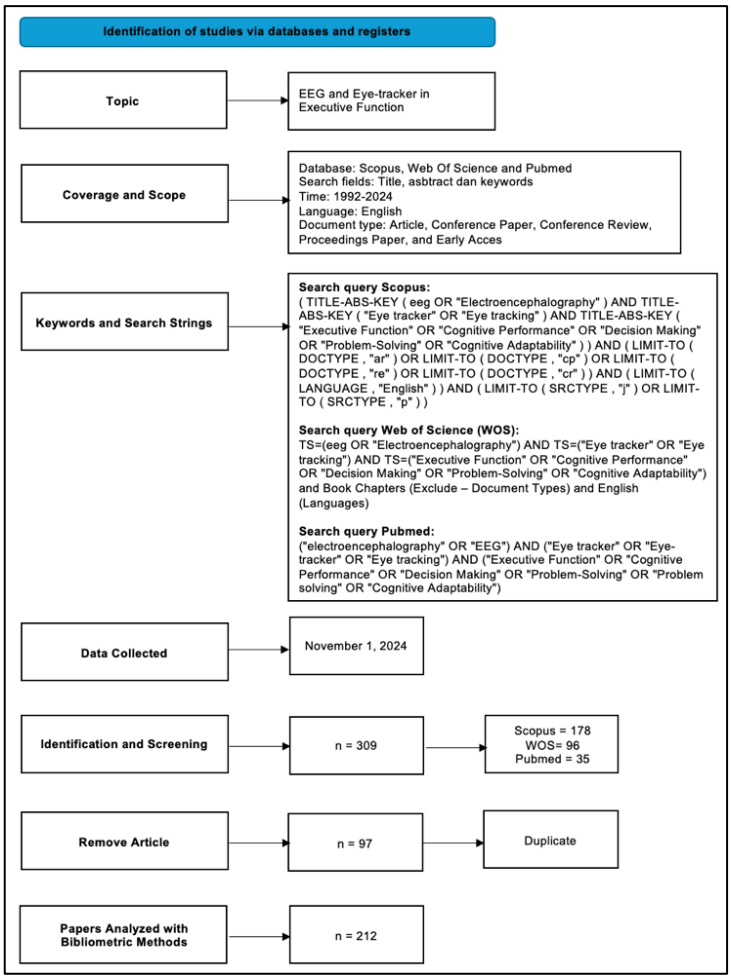

Figure 1. Preparing EEG and Eye-tracker Research Article

Results

Most Influential Author in the Field of Research on the Use of EEG and ET on Executive Function

Based on the bibliometric analysis of publications and citation counts in Table 1, authors who have made significant contributions to EEG and Eye-tracker research on executive function were found. Authors such as Anja, A., Davis, F., and Dimoka, A., are listed as the authors with the highest citations, reaching 235 citations despite having only one publication each. This confirms that the quality of their research is highly influential in expanding the literature in this field. Their research shows a high level of impact despite their lower quantity productivity.

Table 1. Authors with top Publications and citations

Rank	Productive Author	TP	TC	h	g	m	Most Cited Authors	TC	TP	h	g	m
1	Baglio, F	4	16	2	4	0.400	Anja, A	235	1	1	1	0.077
2	Borgnis, F	4	16	2	4	0.400	Banker, R	235	1	1	1	0.077
3	Cipresso, P	4	16	2	4	0.400	Benbasat, I	235	1	1	1	0.077
4	Riva, G	4	16	2	4	0.400	Davis, D	235	1	1	1	0.077
5	Cabral, S C A	3	28	3	3	0.600	Davis, F	235	1	1	1	0.077
6	Da Silva, A	3	28	3	3	0.600	Dennis, A	235	1	1	1	0.077
7	Fabrikant, S	3	19	3	3	0.273	Dimoka, A	235	1	1	1	0.077
8	Rossetto, F	3	16	2	3	0.500	Gefen, D	235	1	1	1	0.077
9	Chen, X	3	6	1	2	0.200	Gupta, A	235	1	1	1	0.077
10	Liu, Z	3	42	1	3	0.200	Kenning, P	235	1	1	1	0.077

Notes. TP = Total Publications; TC = Total Citations; h = h-index; g = g-index; m = m-index.

In contrast, authors such as Baglio, F., Borgnis, F., Cipresso, P., and Riva, G., who have four publications each, show higher productivity. However, their total citations (16 citations) are in the moderate category when compared to the contributions of the highest-cited authors. Other authors such as Cabral, S. C. A. and Da Silva, A., who have three publications each, register a higher total of citations (28 citations), showing productivity consistent with a greater level of impact than their peers who have the same number of publications.

This analysis highlights the importance of considering not only the number of publications, but also their quality and impact on the development of EEG and Eye-tracker research. For example, Anja, A., and his colleagues made a major contribution through a single highly cited work, while Baglio, F., and his group showed broader productivity but with lower citation impact. In this context, the study suggests combining high productivity with in-depth research quality to enhance the EEG and Eye-tracker literature on executive

functions. Thus, future understanding and applications of these technologies are expected to develop further through a balanced combination of productivity and quality in ongoing research.

Author Collaboration Network in the Field of Research on the Use of EEG and ET in Executive Function

Several major collaboration clusters contribute to the development of research in this area, as shown by the visualization of the collaboration map in EEG and eye-tracker research related to executive functions. Baglio, F. and Rossetto, F. belong to the most common collaboration cluster, which shows their interconnectedness and their emphasis on important elements in neurocognitive research. Both in terms of productivity and relevance of their research, this group is a prominent center of collaboration. In contrast, Cabral, S. C. A. and Carneiro, D. demonstrate efforts to develop innovative empirical approaches. The aim of their collaboration is to develop techniques and methodologies that support the investigation of the relationship between visual cognition and executive function. It appears that other groups, such as Chen, C. and Liu, Y., are helping to expand insights into the validity of measurement tools and the applicability of technology in evaluating executive function.

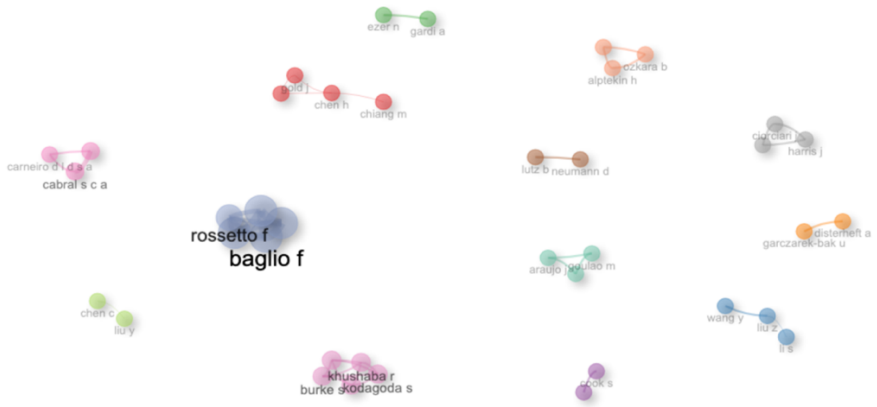

Figure 2. Collaboration Map in EEG and Eye-tracker Research

Alptekin, H., and Ozkara, B.'s group, along with a couple of collaborators such as Lutz, B., and Neumann, D., make more specialized contributions to the application of EEG and eye surveillance in various fields. They seem to concentrate on the applicative approach, especially in looking at how different variables affect the outcome of the study. In addition, pairs such as Wang, Y. and Liu, Z. are involved in international collaborations, which shows the importance of a multidisciplinary perspective in this research. In their method, the understanding of executive function is based on socio-economic and cultural aspects. The Khushaba, R. cluster, with Burke, and Skodagoda, S., contributed greatly to research centered on the development of EEG

technology. Their focus on the combination of theory and application helps strengthen the foundation of neurocognitive research in this area. Overall, this collaboration map shows that cross-disciplinary synergies and contributions from different clusters resulted in EEG and eye-tracker research on executive function. This research strengthens the theoretical basis and opens up new opportunities for technological applications that support cognitive development and executive function.

Most Productive Institution in Research in the Field of EEG and ET Use of Executive Function Research

Zhejiang University ranked first with a total of 8 articles based on institutional productivity data. This shows that the university is the most productive in EEG and eye surveillance research related to executive function. The university greatly contributes to the development of cross-disciplinary research focused on the application of neurocognitive technologies. The University of Pennsylvania produced seven articles in second place. The institution is renowned as one of the leading research centers supporting the development of theories and applications of executive function, particularly through EEG and eye-tracker technologies. Research conducted there often has a major impact on the academic literature.

Table 2. Most Productive Institutions.

Rank	Institutions	Total Article
1	Zhejiang Univ	8
2	University Of Pennsylvania	7
3	Poznan Univ Econ and Business	6
4	Univ Liverpool	6
5	Mcgill University	5
6	Univ Cattolica Sacro Cuore	5
7	Virginia Commonwealth Univ	5
8	Boston Univ	4
9	Indian Inst Technol Madras	4
10	King's College London	4

The University of Liverpool and Poznan University of Economics and Business came in third, with 6 articles each. Both institutions show that applying a multidisciplinary approach is key. The University of Liverpool addresses neurocognitive aspects and their applications in various fields, while the University of Poznan focuses on the relationship between cognition and economics. The three universities McGill, Università Cattolica del Sacro Cuore, and Virginia Commonwealth University have five articles in the next ranking. These three institutions consistently contribute to the development of research. The focus of this research ranges from theoretical studies to effective applications of EEG technology and eye surveillance.

The list is completed with four articles from King's College London, Boston University, and the Indian Institute of Technology Madras. These institutions have made significant contributions, especially in adding technical and global perspectives to executive function research. However, their productivity is lower than the institutions at the top of the rankings. Overall, these data show that institutions around the world are focusing on EEG and eye-tracker research on executive function. The geographical spread of research in this area is shown by the dominance of institutions in North America, Europe, and Asia. This shows the importance of interdisciplinary and cross-regional cooperation in the development of these neurocognitive studies.

Most Productive Countries in Research in the Field of EEG and ET Use of Executive Function Research

Table 3 and figure 3 data show that the USA is the most productive as well as the most impactful country in research related to eye monitoring and EEG on executive function. The USA ranked first in both categories with 102 publications and 463 citations. The citation per publication (S/P) ratio of 13.20 indicates the high quality of the research and the great contribution of the USA to enrich the literature in this field. China's research production took second place with 56 publications, but its level of influence was slightly lower, ranking 7th with 158 citations and an S/P ratio of 7.20. This suggests that, despite its high productivity, China's research may have received less widespread academic attention compared to other countries.In contrast, Germany had 23 publications (ranking 6th in productivity) and had great influence with 314 citations (ranking 2nd) and an S/P ratio of 26.20. The high citation ratio indicates that German research is often an important reference in the relevant literature. With 42 publications and 276 citations, the United Kingdom (UK) is ranked third in productivity.

Research from the United Kingdom shows a balance of quantity and quality with an S/P ratio of 19.70, making it one of the main contributors to the development of the sector. In terms of productivity, Italy and Australia rank next, with 35 publications and 29 publications respectively. Australia is ranked 4th with 240 citations and an S/P ratio of 21.80, while Italy is ranked 5th with 211 citations and an S/P ratio of 19.20. This data shows that, although their productivity is slightly lower compared to the United States and the United Kingdom, these two countries still have a globally recognized research reputation. Countries such as Switzerland, Korea and the Netherlands show significant influence despite having only a few publications. For example, Switzerland has an S/P ratio of 29.70, which is the highest on this list, indicating outstanding research quality; Korea also excels with an S/P ratio of 47.70, showing that despite only a few publications research from Korea is highly influential. In contrast, some countries such as Spain, Poland, and Brazil have moderate levels of productivity but lower influence, with S/P ratios of 7.20-18.10.

Table 3. Countries with Most Citations and Publications

Number	Productive Country	TP	Influential Countries	TC	C/P
1	USA	102	USA	463	13.20
2	China	56	Germany	314	26.20
3	UK	42	United Kingdom	276	19.70
4	Italy	35	Australia	240	21.80
5	Australia	29	Italy	211	19.20
6	Germany	23	Switzerland	178	29.70
7	Spain	19	China	158	7.20
8	Chile	18	Korea	143	47.70
9	Poland	15	Canada	127	18.10
10	Brazil	14	Netherlands	85	17.00

Notes. TP = Total Publications; TC = Total Citations; S/P = Citattions/Publication

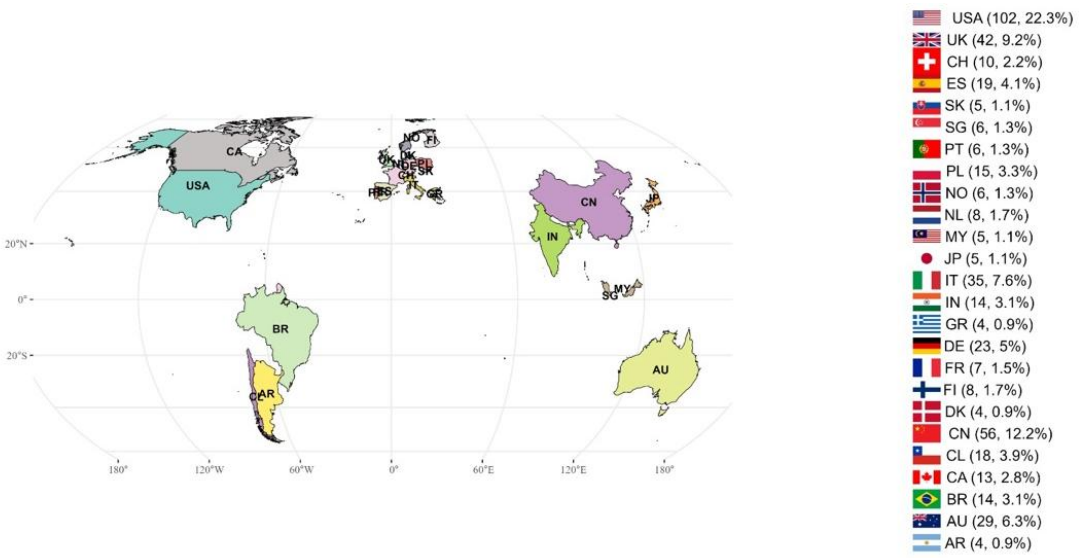

Figure 3. Regional Map of Productive EEG Research Countries

Trends in Research Topics in the Field of Research on the Use of EEG and ET on Executive Function

Studies on the use of EEG and eye-trackers in executive function have undergone significant development with a focus on relevant keywords and research trends over time. The technologies “electroencephalography” and “eye tracking” were highlighted for their frequent appearances, with the highest number of occurrences being 81 and 63, respectively. This suggests that these two technologies are the main tools used to explore executive function. In addition, specialized topics such as “neuromarketing” (18) and “event-related potentials” (11) show more specialized applications. Examples of “neuromarketing” involve the use of “electroencephalography” and “eye-trackers” to understand consumer behavior, while ERPs examine the

brain's response to cognitive stimuli. Additionally, research attention on “cognition” (9) and “executive function” (7) indicates a focus on cognitive processes and executive function as key areas. The use of the term “machine learning” (8) indicates the trend of incorporating advanced technologies in the analysis of EEG and eye-tracker data, which increases the breadth and effectiveness of research. On the other hand, although rarely discussed, “brain-computer interface” shows potential for future development even though it is not a major focus at present.

Table 4. Relevant Keywords for EEG and Eye-tracker Research

Keywords	**Frequency**
electroencephalography	81
eye tracking	63
neuromarketing	18
event-related potentials	11
cognition	9
eye movements	9
machine learning	8
executive function	7
consumer behavior	7
brain computer interface	6

According to the times, the analysis of research trends shows an ever-changing development. To illustrate, “electroencephalography” started to attract attention from 2018 and continued to grow until 2022, confirming its role as a key technology in executive function research. A similar increase in popularity of “eye tracking” occurred on the same trend from 2020, peaking in 2023, indicating a growing interest in this technology. Topics such as “neuromarketing” and “executive function” received notable attention in 2023, indicating applications that increasingly focus on cognitive and behavioral aspects of humans. However, there is a significant increase in the trend of topics such as “machine learning” and “cognition” through 2024, showing how advanced technologies play a role in supporting more complex data analysis. However, some keywords such as “brain-computer interface” only appear relevant in 2014 without significant progress, indicating that research on this topic is more limited compared to other fields.

Overall, these research trends reflect an increasingly multidisciplinary direction. EEG and ET technologies continue to take center stage for understanding executive function, both in terms of theory and applications in various contexts. Recent trends show the integration of advanced technologies such as machine learning to support more complex and efficient analyses, while specific applications such as “neuromarketing” and “consumer behavior” expand the scope of research beyond the traditional domain of executive function. Thus,

in the future, it is expected that research in this field will continue to evolve with more holistic and innovative approaches, expanding our understanding of cognitive dynamics and human behavior as well as its practical applications.

Table 5. Trends in EEG and Eye-tracker Research Topics

Keywords	Frequency	Year (Q1)	Mid Year (Q2)	Year (Q3)
electroencephalography	81	2018	2021	2022
eye tracking	63	2020	2021	2023
neuromarketing	18	2020	2022	2023
event-related potentials	11	2017	2019	2020
cognition	9	2019	2021	2024
eye movements	9	2013	2019	2020
machine learning	8	2021	2022	2024
executive functions	7	2020	2021	2023
consumer behavior	7	2019	2021	2022
brain computer interface	6	2014	2014	2014

Journal that Produces Research in the Field of Research on the Use of EEG and ET on Executive Function

Figure 4 shows the significant growth in publications of EEG and Eye-tracker research on executive function, with the dominance of five major journals: Neuropsychologia, Frontiers in Neuroscience, Sensors, PLoS One, and IEEE Access. Since 2015, Neuropsychologia has been an important platform focusing on the integration of EEG and Eye-tracker technologies in understanding executive function, making it a journal that made early and significant contributions in this field. Frontiers in Neuroscience is rapidly growing as one of the leading journals, presenting a wide range of neuroscience-based research relevant to this topic. In the 2018-2020 period, Sensors began to make major contributions, bringing a multidisciplinary approach with a focus on innovative technologies to enhance behavioral and cognitive studies. These publications show increased attention to the role of technology in understanding executive function.

Meanwhile, PLoS One and IEEE Access reinforce the trend with consistent contributions to technology-based research and innovative methods. PLoS One focuses on exploratory multidisciplinary studies, while IEEE Access pays particular attention to technological applications and innovative approaches relevant to executive function research. Both journals support the development of practical applications in neuropsychology, education, and cognitive behavioral studies. The dominance of these five journals reflects the significant growth trend in EEG and Eye-tracker research, which not only improves research methodologies but also

broadens insights into executive function. Their role demonstrates the increasingly complex and multidisciplinary dynamics of scientific development, in which technology plays a key role. Taken together, these five journals not only support the rich and focused literature on executive function research but also point to the future direction of the field. This trend confirms that the integration of technology with multidisciplinary approaches will continue to drive significant advances, opening up new research opportunities in a variety of related fields.

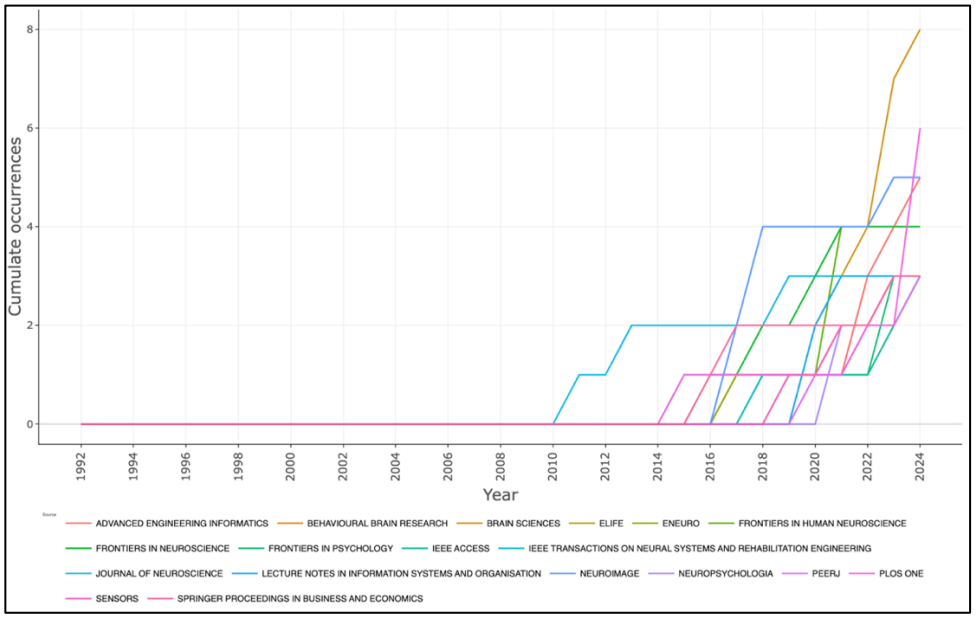

Figure 4. Sources of EEG and Eye-tracker Articles Over Time

Research Developments in the Field of Research on the Use of EEG and ET on Executive Function

Figure 5 displays the growth in the number of research publications on the use of EEG and eye-trackers in relation to executive function between 1992 and 2021. In the early phase, from 1992 to 2000, the graph shows a very minimal publication rate, with almost no research activity recorded. This suggests that at that time, the use of EEG and eye-trackers in executive function research was not yet a major focus. Perhaps, the supporting technology was still limited or the high cost of research was a major deterrent. From 2001 to 2010, a slight increase in the number of publications began to appear, although the growth was still slow. Research in this field began to grow gradually, as technological advances made EEG and eye-trackers more accessible. By the end of this period, around 2010, the graph shows signs of a more consistent increase, although the number of publications is still relatively small compared to the following period.

The period from 2011 to 2015 shows a more pronounced increase. At this stage, the number of publications began to increase more rapidly, with the first peak recorded in 2014. This suggests that interest in this area of

research is growing, perhaps due to the increasing recognition of the role of EEG and eye-trackers in understanding executive function. In addition, advances in methodology and the use of these tools in cognitive contexts have greatly contributed to the increased interest in research. The greatest increase occurred between 2016 and 2021, where the graph shows a significant spike, especially starting in 2018. This increase may be triggered by rapid technological advancements, the adoption of EEG and eye-trackers as standard tools in neuroscience research, as well as a higher awareness of the importance of executive functions in various aspects of life. In 2021, the number of publications reached its highest point, reflecting the peak of interest and research contributions on this topic. Overall, this graph shows how EEG and eye-tracker research in executive function has evolved from an under-the-radar topic to one of the fastest growing fields in the last decade.

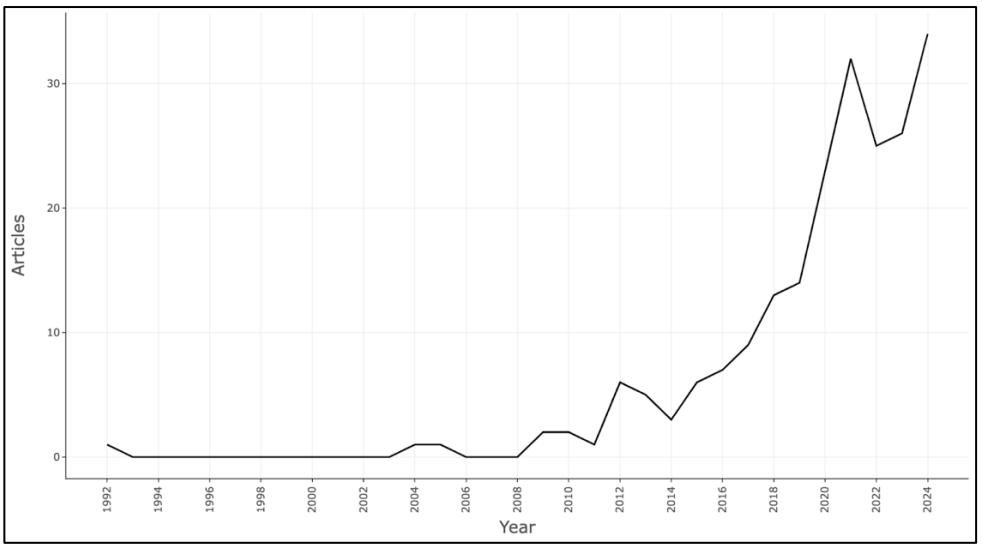

Figure 5. Development of EEG and Eye-tracker Research Over Time

Papers that support the concept of Research on the Use of EEG and ET on Executive Function

Table 6 lists the articles with the most citations that support research on the use of EEG and Eye-tracker on executive function, with the main indicators being total citations (TC) and normalized citations (N/TC). The highest-cited article is by Dimoka et al. (2012), which discusses product uncertainty in online marketplaces, with 235 citations and 18.08 total citations per year. This article shows high relevance in linking cognitive aspects with EEG-based approaches. Polanía et al. (2014) and Lee et al. (2018) came in second and third place, with 150 and 139 citations, respectively. Polanía et al. highlighted the role of neural oscillations in perception- and value-based decision-making, whereas Lee et al. introduced an EEG-EOG-based spelling system with visual feedback. This work is highlighted for its innovative approach in incorporating EEG technology to support practical applications.

Table 6. Most Cited Articles

First Author	Article Title	TC	TC/Year	N/TC
Dimoka, A	Dimoka, A., Hong, Y., & Pavlou, P. A. (2012). On product uncertainty in online markets: Theory and evidence. *MIS quarterly*, 395-426. https://doi.org/10.2307/41703461	235	18.08	3.81
Polanía, R	Polanía, R., Krajbich, I., Grueschow, M., & Ruff, C. C. (2014). Neural oscillations and synchronization differentially support evidence accumulation in perceptual and value-based decision making. Neuron, 82(3), 709–720. https://doi.org/10.1016/j.neuron.2014.03.014	150	13.64	2.80
Lee M	Lee, M., Williamson, J., Won, D., Fazli, S., & Lee, S. (2018). A High Performance Spelling System based on EEG-EOG Signals With Visual Feedback. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 26*, 1443-1459. DOI:10.1109/TNSRE.2018.2839116	139	19.86	3.75
Harris, J	Harris, J. M., Ciorciari, J., & Gountas, J. (2018). Consumer neuroscience for marketing researchers. *Journal of consumer behaviour*, *17*(3), 239-252. https://doi.org/10.1002/cb.1710	106	15.14	2.86
Schneider, C	Schneider, C., Fulda, S., & Schulz, H. (2004). Daytime variation in performance and tiredness/sleepiness ratings in patients with insomnia, narcolepsy, sleep apnea and normal controls. *Journal of sleep research*, *13*(4), 373–383. https://doi.org/10.1111/j.1365-2869.2004.00427.x	95	4.52	1.00
Debie, E	Debie, E., Fernandez Rojas, R., Fidock, J., Barlow, M., Kasmarik, K., Anavatti, S., Garratt, M., & Abbass, H. A. (2021). Multimodal Fusion for Objective Assessment of Cognitive Workload: A Review. IEEE Transactions on Cybernetics, 51(3), 1542-1555. [8846583]. https://doi.org/10.1109/tcyb.2019.2939399	93	23.25	7.48
Wieber, F	Wieber, F., Thürmer, J. L., & Gollwitzer, P. M. (2015). Promoting the translation of intentions into action by implementation intentions: behavioral effects and physiological correlates. *Frontiers in human neuroscience*, *9*, 140516. 10.3389/fnhum.2015.00395	93	11.57	2.18
Stasi, A	Stasi, A., Songa, G., Mauri, M., Ciceri, A., Diotallevi, F., Nardone, G., & Russo, V. (2018). Neuromarketing empirical approaches and food choice: A systematic review. *Food research international*, *108*, 650-664. 10.1016/j.foodres.2017.11.049	81	11.57	2.18
Khushaba, R	Khushaba, R. N., Greenacre, L., Kodagoda, S., Louviere, J., Burke, S., & Dissanayake, G. (2012). Choice modeling and the brain: A study on the Electroencephalogram (EEG) of preferences. *Expert Systems with Applications*, *39*(16), 12378-12388. 10.1016/j.eswa.2012.04.084	79	6.08	1.28
Savage, S	Savage, S. W., Potter, D. D., & Tatler, B. W. (2013). Does preoccupation impair hazard perception? A simultaneous EEG and eye tracking study. *Transportation research part F: traffic psychology and behaviour*, *17*, 52-62. 10.1016/j.trf.2012.10.002	70	5.83	1.86

Keterangan. TC = total citation; TC/Year= total citation per year; N/TC = normalization of total citations

The article by Harris et al. (2018), which discusses consumer neuroscience, made a significant contribution with 106 citations and 15.14 total citations per year, highlighting the application of EEG in understanding consumer behavior. Meanwhile, the work of Schneider et al. (2004) presents a unique perspective on daily performance variations in the context of sleep disorders, albeit with a lower number of citations (95). The article by Debie et al. (2019) registered the highest total citation value per year (23.25) with a focus on assessing cognitive load through multimodal fusion, reflecting the strength of the multidisciplinary approach. Overall, these articles highlight strong trends in EEG and Eye-tracker research, reflecting significant influence in developing theoretical and practical insights into executive function. Their contributions not only broaden the scope of the literature, but also emphasize the importance of innovative technologies in supporting behavioral and cognitive research.

Key concepts of the field EEG and ET Usage Research on Executive Function

EEG and ET Usage Research on Executive Function was analyzed using thematic maps and factor analysis to uncover patterns and relationships in the literature. Thematic maps visualize interrelationships between topics and trends, while factor analysis explores hidden patterns between variables. By referring to Michel Callon's framework, which includes centrality, density, and rank centrality, this approach provides an overview of the research structure as well as identifying key themes for further development (Callon et al., 1983; Callon, 1986; Callon, Courtial, & Laville, 1991).

In this study, 6 clusters were identified (figure 6), each of which provides specific information. Cluster 1 connects eye tracking, EEG, and cognition, which is relevant to the research on the Use of EEG and ET on Executive Function. The combination of eye tracking and EEG enables in-depth analysis of cognitive processes in executive functions, such as attention and decision-making, by monitoring brain activity and eye movements simultaneously. Characterized by high density and high relevance, cluster 1 focuses on the research base of EEG and Eye-tracker in the context of cognition. Cluster 2 highlights Decision Neuroscience with keywords Eye and Neurophysiology, directly related to EEG and ET research on Executive Function. The use of EEG and eye tracking helps understand the neurophysiological processes underlying decision-making and executive function, by monitoring the interaction between the brain and eye movements. Cluster 2 characteristics have high depth (density) but lower relevance (centrality), describing more specific topics in research related to decision making and eye physiology.

Cluster 3 focuses on Assessment, with the keywords Working Memory and Executive Functions, which is highly relevant to EEG and ET research on Executive Function. The use of EEG and eye tracking in this research allows for a more in-depth assessment of working memory capacity and executive functions, as well

as how these two aspects interrelate in the context of decision-making and information processing. The characteristics of this cluster focus on evaluation, working memory and executive function, with in-depth development but lower relevance. Cluster 4 focuses on Neuromarketing, with the keywords Consumer Neuroscience and Marketing, which is concerned with the use of EEG and ET in understanding executive function in consumer behavior. This research helps uncover the influence of attention and decision-making on consumer responses, as well as the cognitive processes behind purchase decisions. The characteristics of this cluster are high density and relevance, illustrating a theme that is already rapidly growing and widely applied in a marketing context.

Cluster 5 focuses on Decision Making and Pupil Dilation, which is related to the use of EEG and eye tracking to measure physiological responses during decision making. This research reveals how pupil changes and brain activity interact in support of executive functions such as information processing and decision making. The characteristics of this cluster are low density and low relevance, suggesting that this topic may be on the wane or developing less. Cluster 6 focuses on Eye Movements, Visual Search, and Attention, which relates to the use of EEG and eye tracking in executive function research. Together they help to understand how eye movements and attention relate to brain activity when performing tasks that involve visual information processing and decision-making. The characteristics of this cluster focus on visual processing and attention, with high density but lower relevance compared to other themes.

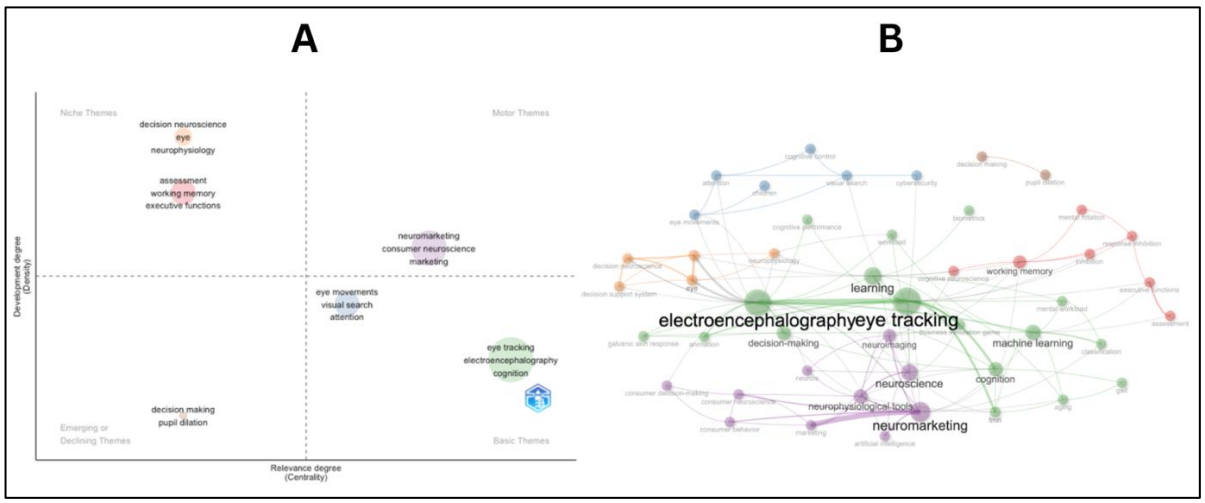

Figure 6. Cluster-Based Thematic Map in EEG and Eye-Tracking

Multiple Correspondence Analysis (MCA) complements factor analysis by visualizing relationships between categorical variables, such as keywords, thus facilitating the exploration of complex data. This technique is often used in bibliometric studies to analyze the co-occurrence of keywords, revealing the intellectual structure within the research domain (Chatzipetrou & Moschidis, 2016; Cankül & Keskin, 2022). Together with factor

analysis, MCA provides a comprehensive framework for bibliometric analysis, which supports a deeper understanding of academic outcomes and research dynamics. The word maps generated from MCA analysis use color to depict clusters that reflect subfields or topics that often co-occur, providing insights into research focus and literature trends. This map helps researchers identify key concepts, significant trends, and areas that require further investigation in EEG and ET research on Executive Function. In addition to being an exploratory reference, the map also guides in formulating future research directions and enriches understanding of the complex interactions between concepts in the field.

The results of the MCA analysis (figure 7) in this study revealed six clusters. Cluster 1 represents a red display that highlights diverse aspects of research on the use of EEG and ET tools in the context of executive function. It includes keywords such as "eye.tracking," "electroencephalography," "cognition," "eye.movements," "machine.learning," "assessment," "decision.making," "fmri," "learning," "visual.search," "attention," "working.memory," "workload," "aging," "cognitive.control," "cognitive.workload," "consumer.behavior," "executive.functions," "gait," "galvanic.skin.response," "inhibition," "mental.rotation," "mental.workload," "neurophysiology," "pupil.dilation," "response.inhibition," "animation," "arousal," "business.simulation.game," "children," "classification," "cognitive.neuroscience," "cognitive.performance," "consumer.decision.making," "cybersecurity," "dyslexia," "epilepsy," "experiment," "eye.movement.related.potentials," "facereader," "facial.expression," "fnirs," "functional.networks," "higher.education," "human.factors," "infant," "information.overload," "lpp," "magnetic.resonance.imaging," "multimodal.data.fusion," "n1," "n170," "n2," "n400," "p3," "performance," "product.reviews," "purchase.intention," "saccades," "serious.game," "spatial," "speech," "theta.oscillations," "training," "traumatic.brain.injury," "valence," and "vision".

Cluster 2 represents a blue display, including keywords such as "neuromarketing," "consumer.neuroscience," "marketing," "neuroscience," "neurois," "artificial.intelligence," "marketing.research," "neuro.tourism," and "neuroscientific.tools." Cluster 3 represents a green display, encompassing keywords such as "neuroimaging," "neurophysiological.tools," "physiological.tools," and "tools." Cluster 4 represents a purple display, containing keywords like "biometrics," "gender," and "social.goal.models." Finally, Cluster 5 represents an orange display, featuring keywords such as "decision.neuroscience," "eye," "tracking," "decision.support.system," and "fitradeoff.method."

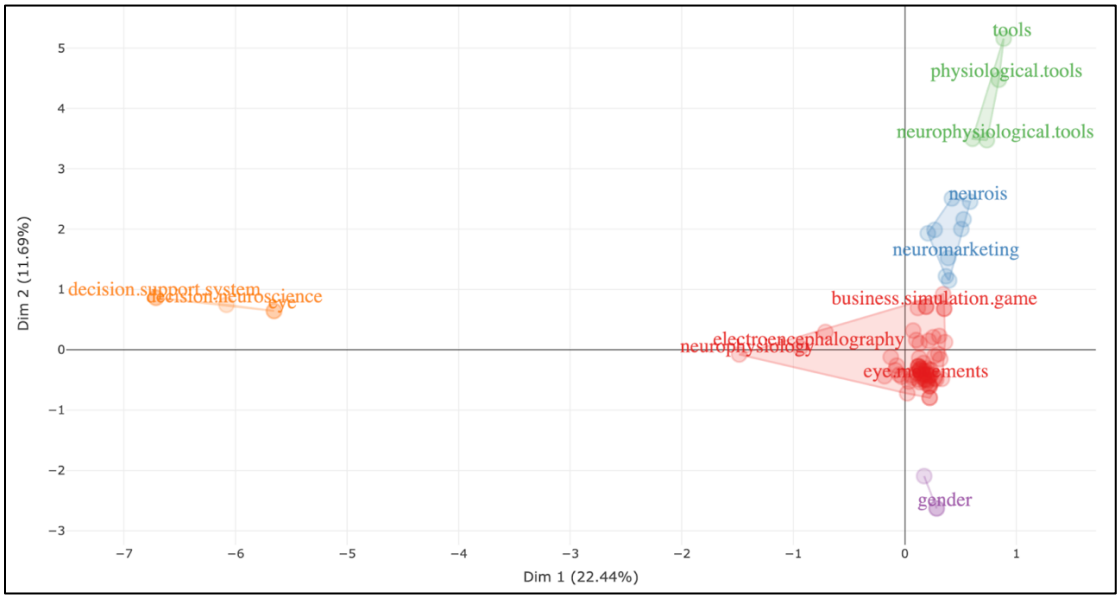

Figure 7. Keyword Map in EEG and Eye-Tracking Research

Discussion

of "electroencephalography (EEG) and eye tracker (ET)" with executive function in cognitive performance. The research identifies key authors, highlights leading universities and countries contributing to the field, explores trends in research topics related to "electroencephalography (EEG) and eye tracker (ET)" and executive function, tracks the development of research over time, and evaluates the types of publications that have been critical in supporting the concept of using "electroencephalography (EEG) and eye tracker (ET)" with executive function in cognitive performance, along with the main ideas in this research field.

This study aims to further investigate the outcomes related to the application of "electroencephalography (EEG) and eye tracker (ET)" in executive function and cognitive performance, as well as their significance and relevance to advancing research in this domain. As the scientific field exploring EEG and ET continues to grow, the focus on measuring executive function drives academic inquiries into related areas. Therefore, it is anticipated that through historical analysis and a research framework, the development of knowledge on the use of "electroencephalography (EEG) and eye tracker (ET)" in executive function within cognitive performance can be mapped.

The findings of this study reveal several aspects related to "electroencephalography (EEG) and eye tracker (ET)" in executive function. The first finding highlights the most influential authors in this research area and identifies the factors affecting the impact of publication size on the development of research ideas. This is evident from the top 10 authors ranked highest in studies related to "electroencephalography (EEG) and eye

tracker (ET)" in executive function. Anja, A., Davis, F., and Dimoka, A., with 235 citations from a single publication, occupy the top position due to their work examining product uncertainty in online markets using EEG, which connects cognitive aspects to decision-making in uncertain environments. Their research is highly relevant and innovative in applying EEG technology to understand consumer behavior, making it a key reference in this field.

On the other hand, Baglio, F., Borgnis, F., Cipresso, P., and Riva, G., despite having four publications, have garnered only 16 citations. This indicates that although their productivity is high, their work is more specific and focused on narrower fields, such as sleep disorders and mental health, limiting its impact on the development of the "electroencephalography (EEG) and eye tracker (ET)" literature in the context of executive function. This finding highlights that in research on "electroencephalography (EEG) and eye tracker (ET)," the quality of relevant content, innovation in connecting technology with real-world issues, and the relevance of the topic play a more critical role in determining the impact of the research than merely the number of publications an author produces.

The next findings can be observed through the most productive institutions in "electroencephalography (EEG) and eye tracker (ET)" research on executive function, reflecting success in building multidisciplinary collaborations and global relevance. Zhejiang University emerges as the most productive institution with eight articles, focusing on neurocognitive applications, while the University of Pennsylvania, with seven articles, contributes significantly through the integration of EEG and ET theories and technologies with broad impact. The University of Liverpool and Poznan University of Economics and Business, each with six published articles, adopt multidisciplinary approaches, such as combining neurocognition with economics. The dominance of institutions in North America, Europe, and Asia underscores the importance of cross-regional collaboration in addressing global challenges. These results highlight that high productivity must be accompanied by relevant contributions to strengthen neurocognitive literature on a global scale.

The most productive countries and the geographical distribution of research on "electroencephalography (EEG) and eye tracker (ET)" in executive function are also key findings of this study. The analysis of national productivity in this field highlights the crucial role of the combination of quantity, quality, and research impact. The United States leads with 102 publications and 463 citations, reflecting the strength of its research infrastructure, substantial funding, and extensive cross-institutional collaboration networks, which produce influential literature that serves as a global reference. China, despite its high productivity with 56 publications, records only 158 citations, indicating that its research is more specific or less integrated into international academic networks. Conversely, Germany, with just 23 publications, achieves 314 citations, demonstrating a focus on high-quality and globally relevant research, making it a key reference in the field. These findings

emphasize the importance of international collaboration strategies, the relevance of findings, and a focus on quality to lead EEG and ET literature.

Another finding of this study is the trend in research topics related to "electroencephalography (EEG) and eye tracker (ET)" in executive function. The analysis of research trends in the use of "electroencephalography (EEG) and eye tracker (ET)" for executive function reveals that these two technologies have become central to the field, with EEG appearing 81 times and eye tracking 63 times, underscoring their key roles in monitoring brain activity and visual behavior. These trends have grown since 2018 for EEG and 2020 for eye tracking, peaking in 2023, in line with the advancement of understanding human cognitive processes and behavior. Specific topics such as neuromarketing and ERP highlight the application of these technologies in understanding consumer behavior and brain responses to stimuli. The integration of machine learning, with eight mentions, is becoming increasingly popular for analyzing more complex "electroencephalography (EEG) and eye tracker (ET)" data. Meanwhile, research in cognition and executive function continues to emphasize decision-making processes. Overall, these trends reflect an increasingly multidisciplinary direction, integrating advanced technologies and expanding the applications of "electroencephalography (EEG) and eye tracker (ET)" from executive function to other fields such as neuromarketing and artificial intelligence development. This provides a foundation for more holistic and innovative research.

The next finding concerns the journals supporting the research concept of "electroencephalography (EEG) and eye tracker (ET)" in executive function. The dominance of five leading journals in this field reflects their significant role in supporting literature and advancing multidisciplinary technology. "Neuropsychologia", as the primary platform since 2015, has become a key journal focusing on the early integration of EEG and ET in understanding executive function, making it an essential reference for researchers. "Frontiers in Neuroscience" has rapidly grown with a diverse range of neuroscience-based studies, strengthening its position as a leading journal. "Measurement Science and Technology", a journal emphasizing advanced methodologies and measurement innovations, gained prominence between 2018 and 2020. It brings a multidisciplinary approach with a focus on technological advancements, contributing significantly to behavioral and cognitive studies. "PLoS One", emphasizing exploratory multidisciplinary studies, and "IEEE Access", highlighting technological applications and innovative methods, round out this trend with consistent contributions to the development of practical applications in neuropsychology and education. These five journals lead the field by facilitating the publication of research employing innovative approaches and advanced technologies. This dominance underscores that the integration of technology within a multidisciplinary approach is key to broadening insights into executive function and opening new avenues for future research.

The findings related to the development of research on "electroencephalography (EEG) and eye tracker (ET)" in executive function also reveal a significant transformation from a relatively underexplored field to one experiencing rapid growth. In the early stages, publications were minimal due to technological limitations and high costs. Gradual growth became evident as advancements in technology made EEG and ET more accessible and relevant for cognitive studies. A significant surge occurred in subsequent periods, driven by recognition of the potential of EEG and ET in understanding executive function and the integration of advanced technologies such as machine learning. The peak in publication growth reflects the maturation of technology and the increasing application of EEG and ET in education, healthcare, and decision-making. This trend underscores the critical role of EEG and ET as primary tools in multidisciplinary studies of executive function.

Another key finding is the papers supporting the research concept of "electroencephalography (EEG) and eye tracker (ET)" in executive function. The most-cited articles in this area demonstrate significant contributions to expanding the literature and establishing practical applications in the field. One such example is the work of Dimoka et al. (2012), which, with 235 citations, successfully linked EEG technology to understanding cognitive aspects in online market uncertainty, making it a primary reference in the literature. Additionally, the study by Polanía et al. (2014), with 150 citations, introduced an innovative approach through the analysis of neural oscillations for decision-making based on perception and value. These two articles exemplify how EEG- and ET-based research can have a substantial impact by integrating advanced technology into the study of behavior and executive function. This highlights the relevance of these technologies in paving the way for more multidisciplinary and application-oriented research directions.

The core research concept revolving around the utilization of advanced technologies, namely "electroencephalography (EEG) and eye tracker (ET)" in relation to executive function, as demonstrated by the comprehensive results obtained from a thorough analysis, strongly suggests the necessity of focusing on the synergistic integration of EEG and ET technologies to achieve a deeper understanding of complex cognitive processes. These processes encompass critical areas such as attention, decision-making, and working memory. This study strategically incorporates significant factors, including but not limited to density and centrality rankings, meticulously grounded in the framework proposed by Michel Callon, to rigorously evaluate the relevance, significance, and depth of various research themes within this domain. The extensive analysis conducted serves to illuminate and unravel the underlying structure of the intricate relationships among these themes, thereby emphasizing their essential and pivotal roles within the broader literature on executive function. The research identifies six major clusters that build upon these concepts: Eye-tracker, Decision Neuroscience, Assessment, Neuromarketing, Decision Making, and Eye Movements. The primary focus lies on the first cluster, which pertains to the foundational use of EEG and ET in deeply analyzing cognitive processes.

Cluster 1 illustrates the collaboration between "electroencephalography (EEG) and eye tracker (ET)" and cognition, particularly in relation to executive function. ET monitors patterns and directions of eye movements, indicating where visual attention is directed, while EEG records electrical brain activity to uncover the neural mechanisms associated with cognitive functions. The integration of these tools provides a comprehensive approach to investigating the relationship between attention, decision-making, and various aspects of executive function. This approach is crucial for studying executive functions, which encompass complex skills such as planning, attention management, and decision-making. Collecting data from both ET and EEG allows researchers to analyze how the brain interprets information in connection with visual attention, yielding vital insights into human responses in specific situations. The approach supports dual-dimensional analysis: physiologically through EEG, which reveals brain wave patterns related to attention, stress, and decision-making; and behaviorally through ET, which uncovers visual focus and explicit attention. As a result, distinct relationships between brain activity and visual attention can be identified during tasks requiring executive function. The characteristics of this cluster demonstrate a strong connection (close interplay between ET, EEG, and cognition) and significant relevance (critical applications for fundamental cognitive research). This highlights that the combination of ET and EEG not only offers technical insights but also serves as an effective method for exploring and understanding human cognitive processes.

Cluster 2 focuses on "decision neuroscience," exploring brain activity that influences decision-making. This cluster highlights the use of electroencephalography (EEG) and eye tracker (ET) to understand decision-making at the neurophysiological level. EEG records brain activity to reveal neural patterns associated with information processing, weighing options, and reacting to stimuli. Conversely, ET tracks eye movements as indicators of visual attention and information-search strategies during decision-making. The integration of these two methods offers a clear approach to illustrating the relationship between brain activity and visual behavior. This research primarily addresses specific aspects of executive function, particularly decision-making. Neurophysiology clarifies how the brain weighs choices, evaluates risks, and reacts to outcomes, while eye movement data provides direct evidence of how attention is directed. Consequently, this research enhances the understanding of key processes that influence human decision-making. The characteristics of this cluster indicate significant depth (density), reflecting a strong focus on the relationship between brain activity, eye movements, and decision-making, supported by a closely-knit research community. However, the importance or centrality of this cluster is reduced due to its limited scope, which constrains its influence on broader research in executive function or cognition. This positions the cluster as a specialized yet critical subfield within neuroscience research.

Cluster 3 highlights “assessment,” focusing on the evaluation of working memory and executive functions in information processing. This cluster centers on working memory and executive function, two critical cognitive elements essential for decision-making and information processing. Working memory enables the temporary storage and manipulation of information, while executive functions encompass skills such as attention, impulse control, and planning. Research in this cluster investigates how these two elements contribute to cognitive processes, utilizing EEG to track neural activity and eye tracking (ET) to observe patterns in visual attention. The application of EEG and ET facilitates a comprehensive assessment approach. EEG provides insights into brain activity related to working memory capacity and information processing during complex cognitive tasks, while ET reveals how visual attention is allocated and managed. This combination offers valuable understanding of the relationship between brain function and behavior concerning executive functions. The characteristics of this cluster emphasize assessment, focusing on the development of detailed tools and methods to measure working memory capacity and executive functions. These methods allow for thorough analysis, though their application to other studies may be limited due to their specialized focus. This positions the cluster as important for investigating specific subfields but with a smaller impact on the broader context of cognition.

Cluster 4 examines "neuromarketing" and its relationship with brain function in understanding how consumers behave and make choices in marketing. The emphasis is on neuromarketing, a technique that combines principles of consumer neuroscience with marketing to gain deeper insights into consumer actions. Using tools like EEG and eye tracking (ET), this research explores brain functions related to attention, decision-making, and consumer choices. EEG reveals how the brain responds to marketing cues, such as advertisements or products, by capturing emotional responses, focus, and cognitive evaluations. ET tracks where consumers direct their gaze, offering insights into how they navigate product pages or assess advertisement design elements. This integration enables direct examination of how brain activity correlates with consumer viewing behavior, providing valuable perspectives on decision-making processes in the context of marketing.

Executive functions such as managing attention and making decisions play a crucial role in influencing consumer behavior. EEG and ET provide extensive insights into how consumers process information, weigh options, and make purchasing decisions. Consequently, this research uncovers the cognitive mechanisms underlying preferences, engagement, and emotional responses to a product or service. The features of this cluster demonstrate high density, reflecting well-connected themes that bridge neuroscience, marketing, and executive functions. Additionally, its significant importance implies that neuromarketing has rapidly evolved and possesses wide-ranging practical applications in enhancing marketing strategies, including product development, advertisement creation, and improving consumer experiences. This cluster represents one of the fastest-growing areas at the intersection of cognitive science and practical applications.

Cluster 5 focuses on "decision making," particularly examining how individuals respond by emphasizing physical reactions during the decision-making process. This cluster highlights the relationship between decision-making and pupil dilation, a significant area of interest in cognitive research. Pupil dilation serves as a physiological indicator to evaluate reactions to cognitive challenges, attention, and emotions during decision-making. In this research, EEG is crucial for analyzing brain activity associated with information processing, while eye tracking (ET) monitors pupil changes to capture automatic responses. However, due to the method's narrow focus on a single aspect, its scope is more limited than studies that comprehensively address cognition or executive functions. Investigations in this cluster examine specific executive functions, such as how the brain evaluates information and makes decisions in particular situations. While providing useful insights, pupil dilation represents only a small fraction of the broader cognitive processes.

The application of these findings is restricted as they are not easily connected to broader domains, such as working memory, impulse control, or attention. The characteristics of this cluster demonstrate low density, with weaker connections between studies due to its limited and backward-focused scope. Research on pupil dilation typically appears as part of broader studies rather than as a prominent independent topic. Additionally, the low significance suggests that findings within this cluster have limited influence on other research in cognition or executive functions. Its relevance may also be diminished as this subject is currently less popular or advancing as rapidly as other areas in neuroscience or decision-making research.

Cluster 6 focuses on "eye movement" and its relationship with visual search, attention, and how visual information is processed during cognitive activities. This cluster centers on eye movements, visual search, and attention, aiming to understand how visual attention is directed and how critical details are selected during visual tasks. Research in this cluster employs eye tracking to analyze patterns of eye movements, such as saccades and fixations, elucidating methods of visual search and attention direction. Conversely, EEG is used to uncover neural activity related to visual information processing, attention, and decision-making.

The combination of these techniques enables a comprehensive examination of how visual actions relate to brain activity. Regarding executive function, the research emphasizes specific aspects such as visual processing and attention. However, it does not encompass broader aspects of executive function, such as working memory, impulse control, or planning. Consequently, the relevance of this cluster to broader themes in executive function is somewhat limited. The practical applications of these findings are primarily focused on visual contexts, including human-machine interfaces, education, or design. The characteristics of this cluster demonstrate high density, with strong interconnections among studies focusing on eye movements, attention, and visual search. Nevertheless, its importance is comparatively lower than other themes due to its focus on a specific subfield

of executive function. Thus, while this cluster provides valuable insights into visual processing, its impact on the larger field of cognitive research is limited.

Conclusion

This study found that, as a result of increasingly advanced technologies and methodologies, the use of electroencephalography (EEG) and eye tracking (ET) has rapidly developed to study cognitive performance and executive functions. Using bibliometric analysis of 212 articles, the research identifies key contributions from the most productive authors, institutions, and countries in this field. It also explores emerging trends, such as the use of EEG and ET in neuromarketing, decision-making, and the evaluation of executive functions. The results indicate that international collaboration and the integration of advanced technologies, such as machine learning, are key factors driving progress in this industry. Identified research clusters, such as Eye-Tracker, Decision Neuroscience, and Neuromarketing, highlight the potential of EEG and ET to understand complex cognitive components like attention, decision-making, and visual information processing. Overall, the study affirms that a deeper understanding of cognitive processes is needed through multidisciplinary approaches and technological integration. It demonstrates that the use of EEG and ET is beneficial for developing applications in various fields, such as education, marketing, and neuropsychology. Future research is expected to expand the use of these technologies and significantly contribute to exploring more complex cognitive processes.

Limitations

The study presents several limitations that should be considered. One significant challenge lies in the integration of EEG and eye-tracking (ET) methods, as eye movements often cause artifacts that interfere with the quality of EEG data, complicating accurate analysis. Despite technological advancements, the seamless combination of these tools remains a hurdle, necessitating further research and development. Another limitation is the lack of comprehensive bibliometric studies that specifically map trends and research patterns in the integration of EEG and ET for studying executive functions. This gap indicates the need for a more robust strategic framework to guide future research.

Additionally, while EEG and ET technologies have advanced, they still face methodological constraints, such as limitations in EEG signal resolution and the precision of eye-tracking measurements. These constraints may affect the reliability and depth of findings. Geographical imbalance in research contributions is another concern, with the majority of influential studies originating from a few regions, particularly the USA, Europe, and Asia. This dominance may overlook valuable insights from underrepresented regions. Moreover, the

research tends to focus narrowly on specific applications, such as neuromarketing and decision neuroscience, potentially leaving areas like rehabilitation and educational interventions underexplored.

The scope of research topics also reflects a concentration on certain keywords and trends, such as cognition and neuromarketing, which may not fully capture the multidisciplinary potential of EEG and ET. Furthermore, the analysis is limited to publications up to 2024, which might not encompass long-term developments in the integration of these technologies. Addressing these limitations will require a more inclusive, comprehensive, and forward-looking approach to advance research on the application of EEG and ET in understanding executive functions.

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Effect of Peer Tutoring on Biology Achievement Among Secondary School Students

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Abstract

This study investigated the effect of peer tutoring on the biology achievement of secondary school students in Epe Local Government Area (LGA) of Lagos, Nigeria. A quasi-experimental pretest-posttest control group design was adopted for the research. Two research questions and two hypotheses were formulated to guide the study. The sample consisted of two intact classes selected through simple random sampling, comprising 160 Senior Secondary II students. Data were collected using a 30-item multiple-choice Biology Achievement Test (BAT), with a reliability coefficient of 0.75, as determined by the Kuder-Richardson Formula 21 (KR-21). Mean and standard deviation were used to answer the research questions, while ANCOVA and t-test were employed to test the null hypotheses at a 0.05 level of significance. The findings revealed that peer tutoring significantly improved students' biology achievement, with students taught using peer tutoring outperforming those taught through conventional methods. Furthermore, the study found no significant difference in the effect of peer tutoring based on gender, indicating that both male and female students benefited equally from the method. It is recommended that peer tutoring be integrated into biology instruction, alongside other active learning strategies, to enhance students' academic achievement in the subject.

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Introduction

Education systems around the world strive to improve students' academic achievements, particularly in subjects like science, which is critical to global development (Xiong, 2024). Biology, one of the core science subjects, has historically presented challenges to secondary school students due to its conceptual and complex nature (Isma'il & Matazu, 2024). This has led to suboptimal performance in various educational contexts. To address these issues, educators are constantly exploring innovative pedagogical strategies that promote active learning and student engagement (Bhoi, 2024). Peer tutoring, a cooperative learning approach where students assist one another in mastering academic content, has garnered attention as a potential method to enhance achievement in Biology. Numerous studies suggest that peer tutoring can help improve students' understanding of difficult topics and foster an interactive learning environment (Ullah et al., 2018). This study explores the effect of peer tutoring on secondary school students' academic achievement in Biology, focusing on the mechanisms through which peer interactions can positively impact learning outcomes.

In many educational settings, students face significant challenges in grasping complex Biology concepts. Traditional instructional methods, often characterized by teacher-centered approaches, may not fully address individual students' learning needs, contributing to poor performance. To mitigate this, various collaborative learning strategies have been employed, with peer tutoring emerging as an effective alternative (Precious & Feyisetan, 2020). Peer tutoring has been the focus of numerous educational studies due to its potential to improve students' academic outcomes. Ain et al. (2023) describes peer tutoring as an instructional strategy where students work in pairs or small groups to provide mutual assistance, often resulting in improved academic performance for tutors. According to Ullah et al., (2018), peer tutoring in science subjects like Biology promotes higher retention rates, better conceptual understanding, and increased academic achievement. The authors found that when students engaged in peer tutoring, they were more likely to improve their test scores, as the process facilitated the breaking down of complex biological concepts into simpler, more manageable parts. This study examines how peer tutoring can enhance students' achievement in Biology by leveraging peer interactions for better learning outcomes.

Literature Review

Peer tutoring has its roots in collaborative and cooperative learning theories, which emphasize the social aspect of learning (Yang, 2023). Vygotsky's Social Learning Theory posits that students can learn effectively through interaction and shared experiences with their peers. According to Vygotsky, the Zone of Proximal Development (ZPD) is the gap between what a learner can do independently and what they can achieve with guidance from a more knowledgeable peer (Vygotsky, 1978). In peer tutoring, the tutor provides scaffolding that helps the

tutee reach higher levels of understanding and competency in a subject area, such as Biology.Further supported by Constructivist Learning Theory, which holds that learners actively construct knowledge by integrating new information with prior knowledge, peer tutoring allows both tutors and tutees to engage with Biology content through discussion, questioning, and problem-solving (Chuang, 2021). The reciprocal benefits of peer tutoring, where both tutor and tutee experience learning gains, underscore its potential as an effective pedagogical tool.

In secondary education, the need for effective strategies to teach Biology has become increasingly evident, especially as students struggle with abstract and complex content (Elkhidir, 2020). Fakiye (2021) examined the impact of peer tutoring on students' achievement in Biology and concluded that peer tutoring significantly enhanced students' performance compared to those who received only traditional teacher-centered instruction. The researchers attributed this improvement to the interactive nature of peer tutoring, where students could ask questions, receive immediate feedback, and work collaboratively to solve problems. Moreover, Canning et al., (2018) conducted a study on the effectiveness of peer tutoring in Biology and found that peer tutoring contributed to improved understanding and retention of complex biological topics, such as genetics and cell biology. Their findings highlight the importance of peer collaboration in learning difficult subjects, as tutees benefit from explanations that are often simpler and more relatable than those provided by teachers.

Different peer tutoring models, such as same-age and cross-age tutoring, have been explored in various educational contexts. Leung (2018) emphasize that the success of peer tutoring largely depends on how well it is structured and implemented. They noted that well-organized peer tutoring sessions, where both tutors and tutees have clear roles and learning objectives, are more likely to yield positive results. Research by Ogundola, (2016) also supports the use of peer tutoring as a method to foster student autonomy and responsibility in learning. Their study of Nigerian secondary schools revealed that peer tutoring improved students' problem-solving skills, critical thinking, and self-confidence, all of which contributed to better achievement in Biology.

The application of Vygotsky's Social Learning Theory and Piaget's Cognitive Development Theory in peer tutoring frameworks explains how social interactions between students can lead to deeper learning. Hayden(2020)assert that cooperative learning strategies like peer tutoring align with constructivist approaches, where students learn by actively engaging with the material and their peers. Peer tutoring fosters a learning environment where students co-construct knowledge, and the tutor reinforces their understanding by explaining concepts to the tutee. Despite its advantages, peer tutoring is not without challenges. Darling-Hammond et al. (2019), caution that the quality of tutoring may vary depending on the competence and preparation of the tutors. If tutors are not adequately trained or do not fully understand the material, they may provide incorrect information to their peers, which could negatively affect learning outcomes. Additionally, peer relationships

and social dynamics can influence the effectiveness of peer tutoring. As Tan and Evera (2020) note, students may be reluctant to engage with their peers if they feel intimidated or uncomfortable in a tutor-tutee role.

Peer tutoring has emerged as a valuable instructional strategy for improving students' achievement in various subjects, including Biology. Several studies highlight its benefits in enhancing understanding, retention, and student engagement. For instance, Ugwu et al. (2021) demonstrated that secondary school students in Nigeria achieved higher scores in Biology when taught through peer tutoring compared to traditional lecture methods. Peer tutoring encourages active learning, where students explain concepts to each other, reinforcing their knowledge and critical thinking skills (Ain et al., 2023). Eze and Dinneya (2022) reported that peer tutoring fostered a more interactive learning environment, leading to improved academic performance in Biology. However, factors such as tutor competence and content difficulty can impact the effectiveness of this method. Ratanarajah et al. (2020) pointed out that peer tutoring might not always lead to better outcomes when tutors lack sufficient knowledge. Moreover, Ihekwoaba et al. (2020) observed that social dynamics, such as participation inequality between genders, could affect peer tutoring outcomes. Despite these challenges, most studies agree that peer tutoring, when properly structured, significantly enhances Biology achievement, making it a viable instructional strategy for secondary schools.

Peer tutoring presents a promising approach to improving secondary school students' achievement in Biology. By leveraging the collaborative and interactive nature of peer learning, students can better understand and retain complex biological concepts. However, careful planning and implementation are required to ensure its effectiveness, including the proper training of tutors and the establishment of structured tutoring sessions. The problem addressed by the current study investigates the effect of peer tutoring on secondary school students' achievement in Biology looking at the moderating effect of gender.

Research Questions

The following research questions guided the study:

1. What is the difference between the mean achievement scores of students' taught Biology using Peer tutoring method and Lecture method?
2. What is the difference between the mean achievement scores of male and female students' taught Biology using Peer tutoring method and Lecture method?

Hypotheses

The following null hypothesis was tested at 0.05 level of significance.

H_O1: There is no significant difference between the mean achievement scores of students taught Biology using Peer tutoring method and those taught using Lecture method.

H_O2: There is no significant difference between the mean achievement scores of male and female students taught Biology using Peer tutoring method and those taught using Lecture method.

Method

This study employed a quasi-experimental pretest-posttest control group design, which utilized intact classes rather than randomly assigning participants to groups. This approach was necessitated by ethical and practical constraints associated with the educational setting. The design involved two groups: an experimental group that received the intervention and a control group that did not. Both groups completed a pretest prior to the intervention and a posttest following its conclusion.

The sample consisted of two intact Senior Secondary II (SS II) biology classes, selected through simple random sampling to enhance representativeness and reduce potential selection bias. The intervention aimed to measure its impact on students' academic performance and engagement with the subject matter.

Data analysis was conducted using both descriptive and inferential statistical methods. Descriptive statistics, including mean and standard deviation, were used to summarize students' performance in the pretest and posttest. Analysis of Covariance (ANCOVA) was applied to control for baseline differences in pretest scores between the groups, ensuring that observed posttest differences were attributable to the intervention. Furthermore, an independent samples t-test was employed at a significance level of 0.05 to evaluate whether the differences in posttest scores between the experimental and control groups were statistically significant.

This methodological approach ensured rigor and provided a robust framework for assessing the efficacy of the intervention.

Results

Research question 1: What is the difference between the mean achievement scores of students' taught Biology using Peer tutoring method and Lecture method?

The data in Table 1revealed that the mean gain achievement scores of students taught using peertutoring method was 15.33 while that of students taught using lecture method was 9.56. Students taught using peer tutoring has the highest mean gain scores than those taught with lecture methods.

Table 1. Mean Achievement Scores of Students taught biology using Peer tutoring method and Lecture method

Group	Symbol	Pre-Test	Post-Test	Mean Gain
Peer tutoring	N	80	80	15.33
(experimental)	X	12.15	27.48	
	SD	1.44	1.77	
Lecture method (control)	N	80	80	9.56
	X	11.1	20.66	
	SD	0.76	3.25	

N=Number of subjects, X = Mean and SD = Standard deviation

Table 2 shows the achievement of male and female senior secondary school students taught biology using Peer tutoring method and Lecture method. The mean achievement score of male students was 27.34 while the standard deviation was 0.75; the female students have a posttest mean achievement score of 27.56 and the standard deviation of 0.77 in the biology achievement test. This means that gender did not have any effect on the mean achievement scores of students. By implication, gender as a factor did not contribute to the differences in the posttest means scores of the subjects.

Table 2. Mean Achievement Scores of Male and Female Students taught Biology using Peer tutoring method

Gender	N	Mean	SD	STD Error
Male	32	27.34	0.75	0.13
Female	48	27.56	0.77	0.11

N = number of subjects; SD = Standard deviation

Ho1: There is no significant difference between the mean achievement scores of students taught Biology using Peer tutoring method and those taught using Lecture method.

Table 3 shows the ANCOVA of the mean achievement scores of students who experienced peer tutoring and Lecture method in the teaching of biology ($[F_{(302.949)} = .659; p > 0.05]$. The result suggested a statistical significant difference between the peer tutoring method group and the lecture method group. A post-hoc test presented in table 4 indicated the direction of the effect.

Table 3. Analysis of Co-variance on Achievement of Students' taught Biology using Peer tutoring and those taught using Lecturer method

Source	Type III Sum of Squares	Df	Mean Square	F	Sig	Partial eta Squared
Corrected Model	1856.753	2	928.376	166.104	.000	.679
Intercept	1796.216	1	1796.216	321.378	.000	.672
Pre test	.347	1	.347	.062	.804	.000
Post test	1693.218	1	1693.218	302.949	.000	.659
Error	877.491	157	5.589			
Total	95423.000	160				
Corrected Total	2734.244	159				

The result in Table 4 shows that the mean difference between the peer tutoring group and the lecture method group was 6.84, the mean difference between the two groups is statistically significant (p=.000); hence, the null hypothesis 1 is hereby rejected.

Table 4. Pair-wise comparison of student's scores in Biology

Treatment	Mean difference	Std. Error	Sig	95% confidence interval for difference	
				Lower Bound	Upper Bound
Peer tutoring	6.843	.393	.000	-7.619	-6.066
Lecture method	-6.843	.393	.000		

Ho2: There is no significant difference between the mean achievement scores of male and female students taught Biology using Peer tutoring method and those taught using Lecture method.

Table 5: T-test Analysis of Mean Achievement Scores of Male and Female Students taught Biology using Peer tutoring method

Group	N	X	Sd	D f	T- cal	Sig	Decision
Male	3 2	27.34	0.75	7 8	1.27	0.209	Accepted
Female	4 8	27.56	0 .77				

Significant at p<0.05

Table 5 shows that female students (X = 27.56) have higher mean achievement scores than theirmale counter parts (X = 27.34), this difference is however not statistically significant at 0.05 alpha level (t = 1.27; df = 78; p <. 05). Therefore, the null hypothesis 2 is hereby accepted.

Discussion

The research result shows that students taught Biology using peer tutoring tend to achieve higher mean scores compared to those taught through traditional lecture methods. For instance, Ugwu et al., (2021), in their study of Nigerian secondary schools, found that peer tutoring significantly improved students' understanding and retention of complex Biology topics compared to the lecture method. This finding is supported by Ain et al., (2023), who reported similar results in a study conducted across several countries, indicating that peer tutoring fosters greater engagement and allows students to clarify concepts through collaboration, reinforcing their knowledge and critical thinking skills leading to better academic outcomes. Moreover, Eze & Dinneya (2022), in their research on Nigerian secondary school students, demonstrated that peer tutoring led to higher mean achievement scores, as students were more active in their learning process and able to ask questions freely, which is often not the case in the passive lecture environment. Similarly, Fakiye (2021) found that Nigerian students who participated in peer tutoring sessions outperformed their peers who received teacher-centered instruction in Biology, largely due to the interactive nature of the tutoring sessions.

However, some studies present conflicting evidence. Ratanarajah et al. (2020) argued that peer tutoring may not always result in better performance, particularly when tutors lack sufficient subject knowledge. In such cases, the lecture method, delivered by an expert teacher, provided clearer and more structured explanations, leading to better outcomes. Thus, while the majority of studies, both in Nigeria and internationally, support the superiority of peer tutoring in improving Biology achievement, some caution that its effectiveness depends on the tutors' competence and the nature of the material being taught.

Further research result indicates that there is no significant difference in the mean achievement scores of male and female students taught Biology using the peer tutoring method. For example, Ugwu et al., (2024) conducted a study in secondary schools in Nsukka Local Government Area of Enugu State and found that both male and female students benefited equally from peer tutoring, with no significant gender differences in their academic performance. This finding is consistent with the research of AbdulRaheem (2017), who analyzed the impact of peer tutoring and reported that the method was effective for students regardless of gender, as both male and female students experienced similar improvements in achievement. They suggested that the collaborative and supportive nature of peer tutoring creates an inclusive learning environment where both genders are equally engaged and motivated to succeed.

On the contrary, some studies argue against this finding. Ihekwoaba et al., (2020) reported that in certain educational contexts, male students tended to benefit more from peer tutoring than female students, citing social dynamics and participation levels as contributing factors. They suggested that in some cases, male

students were more confident in taking leadership roles during tutoring sessions, which could lead to a slight performance edge. However, Aniaku et al., (2021) found minimal evidence to support a significant gender disparity in peer tutoring outcomes, emphasizing that differences in performance, if any, were more likely attributable to individual student characteristics than to gender.

While peer tutoring offers significant benefits, certain challenges may limit its effectiveness if not properly managed. A primary concern is the risk of misinformation since peer tutors, who are also learners, might unintentionally share incorrect information, potentially leading to misconceptions. This emphasizes the teacher's essential role as a facilitator and quality controller. Through active supervision and timely feedback, teachers can help ensure that students are sharing accurate information. Time management is another concern, as peer tutoring often requires more time than traditional methods, particularly in large classrooms with limited one-on-one attention. To address this, teachers should set clear goals, allocate specific time slots, and define roles within each session, making sessions more focused and efficient. In summary, while peer tutoring fosters an engaging and collaborative learning environment, it demands careful planning and active teacher involvement. By managing these challenges effectively, teachers can help students maximize the benefits of peer tutoring, enhancing their engagement and comprehension.

Conclusion

Based on the findings of this study, peer tutoring significantly enhances students' achievement in Biology compared to traditional lecture methods. By fostering an interactive and collaborative learning environment, peer tutoring allows students to clarify complex concepts, ask questions openly, and learn at their own pace, all of which contribute to improved academic performance. This method proves effective for both male and female students, with no significant gender differences in achievement, demonstrating that peer tutoring is an inclusive and equitable teaching approach.

However, the success of peer tutoring is influenced by several key factors that can either enhance or limit its effectiveness across various contexts. Tutor competence is crucial; tutors with a strong understanding of Biology are more likely to accurately convey concepts, reducing the risk of misinformation. In cases where tutors are less experienced, teacher supervision and structured guidance are essential to ensure information accuracy and conceptual clarity. Classroom size and time constraints also play a significant role. In larger classrooms, it becomes more challenging for teachers to provide oversight, making it necessary to implement smaller, well-organized groups to maintain focus and quality. Additionally, the complexity of the material can affect outcomes; peer tutoring works well for foundational topics, but more complex areas may require added teacher support or supplemental materials.

Despite occasional conflicting evidence, extensive studies in both Nigeria and international contexts generally support the effectiveness of peer tutoring in diverse learning environments. When implemented thoughtfully—taking into account tutor competency, classroom structure, material complexity, and adequate teacher involvement—peer tutoring stands out as a powerful, student-centered instructional strategy for Biology education in secondary schools.

Recommendations

1. Schools should consider incorporating structured peer tutoring programs into their Biology curriculum. Teachers can select capable student tutors, train them on effective tutoring techniques, and supervise tutoring sessions to ensure accuracy and effectiveness.
2. Tutors should receive adequate training to improve their understanding of Biology concepts and enhance their ability to explain these concepts clearly to their peers. This training will help minimize the risk of misinformation and ensure the sessions are productive.
3. Since there are no significant gender differences in the effectiveness of peer tutoring, schools should adopt gender-inclusive strategies that encourage both male and female students to participate actively in peer tutoring programs.
4. Regular monitoring and assessment should be conducted to evaluate the impact of peer tutoring on student achievement. Schools should collect feedback from students and tutors to improve the quality of tutoring sessions.
5. Given its success in Biology, peer tutoring can be expanded to other science subjects, such as Chemistry and Physics, to enhance student learning and performance in these areas as well.

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