Available online at www.ijournalse.org

Emerging Science Journal

(ISSN: 2610-9182)

Vol. 9, Special Issue, 2025

"Emerging Trends, Challenges, and Innovative Practices in Education"

Teacher Attitudes and Barriers to GeoGebra Adoption in Secondary Mathematics Education

Georgia Vlachoni [1, 2], Hera Antonopoulou [1], Zoe Karanikola [3*], Constantinos Halkiopoulos [1*]

[1] *Department of Management Science and Technology, University of Patras, 265 04 Patras, Greece.*

[2] *General Music School of Patras, 263 35 Patras, Greece.*

[3] *Department of History-Archaeology, University of Patras, 265 04 Patras, Greece.*

Abstract

Objectives: This study investigates GeoGebra implementation patterns and identifies facilitators and barriers to adoption among Greek secondary mathematics teachers using the Technology Acceptance Model (TAM) framework. *Methods:* A cross-sectional survey of 82 secondary mathematics teachers in Western Greece was conducted during June-July 2023 (87.7% response rate), using a validated questionnaire to assess actual usage, perceived usefulness, ease of use, and attitudes toward implementation across four mathematical domains. *Findings*: Results revealed an implementation paradox: low actual usage (M = 2.21) despite positive attitudes (M = 3.53) and recognized usefulness (M = 3.42). Domain-specific variation showed moderate Geometry implementation (M = 2.77) versus very low Statistics adoption (M = 1.77). Regression analysis explained 40.1% of the variance in usage through Ease of Use (β = 0.360) and Attitude (β = 0.281). B2-level ICT certification emerged as a critical threshold for implementation success. *Novelty*: This study introduces the Contextual Implementation Cascade Framework (CICF), which explains multi-level barriers to educational technology adoption and demonstrates that positive attitudes cannot overcome systemic infrastructural and institutional barriers without comprehensive professional development.

Keywords:

GeoGebra; Teaching Scenarios; Secondary Mathematics Education; Technology Acceptance Model; Gamification; ICT Integration; Teacher Professional Development; Implementation Barriers; Educational Technology Adoption; Greece.

Article History:

Received:	22	November	2025
Revised:	20	February	2026
Accepted:	03	March	2026
Published:	26	March	2026

1- Introduction

Despite three decades of ICT integration initiatives in education, a persistent implementation gap exists between technological availability and classroom adoption—nowhere is this more apparent than in secondary mathematics education. While dynamic mathematics software like GeoGebra offers unprecedented opportunities for visualization, exploration, and conceptual understanding, actual classroom implementation remains disappointingly low across diverse educational contexts [1, 2]. This study investigates why this gap persists. GeoGebra represents the culmination of ICT evolution in mathematics education. Early ICT integration (1970s-1990s) focused on computational tools and computer-assisted instruction. The subsequent shift toward interactive learning environments (2000s-2010s) emphasized dynamic visualization and student-centered exploration. GeoGebra embodies this evolution: free, multi-platform software that integrates algebraic, geometric, graphical, and statistical representations in a single dynamic environment. Yet, as ICT tools have become more sophisticated, the gap between their potential and actual implementation has not narrowed. This paradox motivates our research [3, 4].

---

[*] **CONTACT**: zoekar@upatras.gr; halkion@upatras.gr

DOI: http://dx.doi.org/10.28991/ESJ-2025-SIED1-028

The central research problem can be stated directly: Why do teachers who recognize GeoGebra's pedagogical value fail to implement it in their classrooms? What systemic, institutional, and individual factors explain this implementation-intention gap? Addressing these questions requires moving beyond descriptive accounts of technology availability to examine the complex interplay of factors that facilitate or inhibit adoption in real educational contexts.

1-1- Information and Communication Technologies in Education

Contemporary society is described as a society of knowledge, information, and communication, marked by the availability of various communication technologies for educational purposes. Information and Communication Technologies encompass technologies that support data processing and transmission across various forms of representation, including symbols, images, sounds, and videos [5, 6]. The development of information and communication technology has impacted almost every sphere of human activity, including the economy, communication, trade, finance, entertainment, and information sharing. The informatization of society has completely shifted the paradigms of education [7, 8].

The integration of ICT in education refers to the adoption and use of ICT to enhance the quality of learning experiences and optimize learning outcomes [9-11]. This integration makes classroom lessons more interesting and attractive, where pupils engage in interactive tasks, explore, investigate, discover, collaborate, and develop key skills [12, 13].

1-2- Evolution of ICT Integration Models

The integration of ICT in education has passed through stages with varying philosophies and implementations. Three main models emerged, each rooted in different educational philosophies and technological capabilities of its era [13-16]. The technology focus approach, which originated in 1970, emphasized ICT as a separate subject within the curriculum. The holistic or integrated approach was an evolution towards the use of ICTs for teaching and learning across various disciplines [17-21]. The pragmatic approach, synthesized in the 1990s, integrates features of its predecessors and requires the teaching of at least one computer science class and the use of ICT in other disciplines [22-26]. In Greek schools, implementation strategies differed by education level: the holistic approach was initially proposed for primary education, whereas the pragmatic approach was adopted for secondary education [27-29].

1-3- Gamification Elements in Mathematical Learning

The adoption of gamification elements within mathematics education is a revolutionary approach to overcoming traditional difficulties. Gamification can be described as the use of game elements and strategies in other contexts to improve engagement, motivation, and performance [30-34]. Within mathematics education, gamification involves the development of learning environments in which students engage with mathematical concepts through manipulatives, allowing them to explore, experiment, and receive immediate feedback [35, 36]. Discovery-based learning provides opportunities for students to 'discover' mathematical concepts on their own, giving them far more in-depth experiences than passive reception of information [37-41].

1-3-1- GeoGebra's Gamification Elements: Concrete Examples

GeoGebra incorporates several core gamification elements that distinguish it from traditional mathematical instruction and align with established gamification principles [42]:

Immediate Visual Feedback: When students manipulate geometric objects or modify function parameters, GeoGebra provides instantaneous visual responses. For example, dragging a vertex of a triangle immediately updates angle measures and side lengths, demonstrating geometric relationships in real time. This functions similarly to game mechanics, where player actions produce immediate, visible consequences, creating a tight action-feedback loop that maintains engagement.

Progressive Challenge Scaffolding: GeoGebra's construction tools allow teachers to design increasingly complex tasks that mirror game-level progression. A geometry unit might progress from basic constructions (perpendicular bisector) to intermediate challenges (circumscribed circle of a triangle) to advanced problems (Euler line construction). Each level builds on previous skills, maintaining optimal challenge within students' zones of proximal development.

Discovery-Based Exploration: The dynamic environment enables students to discover mathematical properties through experimentation rather than passive reception. Rather than being told that the angles of a triangle sum to 180°, students can manipulate the triangle's vertices and observe that the sum remains invariant across all configurations, creating an intrinsic satisfaction similar to game-based discovery mechanics.

Interactive Simulations: GeoGebra's probability and statistics tools transform abstract concepts into interactive experiences. Students can run simulations (e.g., repeated coin flips, dice rolls) and visualize how sampling distributions emerge, experiencing statistical concepts as dynamic processes rather than static formulas.

Visual Achievement Indicators: Successfully completed constructions provide visual confirmation of achievement; a properly constructed perpendicular bisector that passes the "drag test" (remaining perpendicular regardless of point movement) provides satisfaction analogous to completing a game level.

1-4- GeoGebra as an Educational Innovation Platform

GeoGebra, which integrates geometry and algebra in its very title, has reached a culmination in educational technology where gamification and mathematical rigor are integrated. This interactive mathematics program can be applied to any area of education, integrating concepts from algebra, geometry, and calculus. GeoGebra is an open-source educational technology that can be used freely for non-commercial purposes [43]. Created by Markus Hohenwarter for his master's degree work at Salzburg University in 2001, it was designed to give students opportunities to experience mathematics through technology [44, 45].

The acceptance of this software by global institutions, its support for more than 40 languages, and its compatibility with every operating system underscore its importance [46, 47]. The environment provides an Algebraic Window where mathematical relations and equations are displayed, a Graphics Window where dynamic geometric graphs are displayed, and an Input Window for direct command entry. Function-specific extensions include spreadsheets, a Computer Algebra System, a 3D Graphics Display, and a Probability Calculator [48, 49].

1-5- Research Gap and Study Significance

A systematic review of existing literature reveals three critical gaps that this study addresses:

First, while GeoGebra has been extensively studied in terms of student learning outcomes and software functionality [3, 4], limited empirical research has examined actual implementation patterns among practicing teachers, particularly the gap between positive attitudes and low usage rates. Most existing studies focus on controlled interventions rather than naturalistic adoption patterns.

Second, the insufficient application of validated theoretical frameworks has hindered our understanding of barriers to technology adoption in resource-constrained educational systems. While the Technology Acceptance Model (TAM) has proven robust in corporate and higher education contexts [50], its application to secondary mathematics education—particularly in systems facing infrastructural challenges—remains underexplored.

Third, the Greek educational context presents unique circumstances that warrant specific investigation. Following a decade of economic constraints that have affected educational infrastructure and professional development opportunities [51], Greek secondary schools operate under conditions in which technological aspirations often exceed institutional capacity.

This study addresses these gaps by applying the TAM framework to systematically investigate GeoGebra adoption among Greek secondary mathematics teachers, providing both theoretical contributions (an extended implementation model) and practical recommendations for overcoming adoption barriers.

1-6- Research Questions

This research is informed by six interrelated research questions:

- RQ1: How often is GeoGebra used in teaching scenarios in mathematics?
- RQ2: What are the most important factors influencing the use of GeoGebra?
- RQ3: Does the frequency of use vary according to socio-demographic factors?
- RQ4: Does the frequency of use vary depending on school type?
- RQ5: To what extent does usefulness and ease of use influence teachers' attitudes?
- RQ6: Can a model predict actual GeoGebra use based on teachers' opinions?

1-7- Article Structure

The remainder of this article is structured as follows. Section 2 presents the theoretical framework, including the Technology Acceptance Model foundations and relevant literature on GeoGebra implementation in international and Greek contexts. Section 3 details the research methodology, including sampling procedures, instrumentation development, and analytical approaches. Section 4 reports the empirical findings organized by research question. Section 5 discusses the theoretical and practical implications, including the proposed Contextual Implementation Cascade Framework (CICF). Finally, Section 6 presents conclusions, limitations, and future research directions.

2- Theoretical Framework and Literature Review

2-1- Global Trends in Educational Technology Integration

The transformation of educational practices through ICT has greatly modified the education environment, shifting not only the modes of teaching but also those of learning. Today, the classroom is no longer limited to pure lecture room education but has become one where students can virtually travel to places, witness the development of events over time, perform complex mathematical calculations quickly, and conduct laboratory tests in 'virtual laboratories' [52-54]. This changeover affects the teaching function itself, as it proceeds from 'knowledge transmitter' to 'guide, facilitator, advisor, or motivator.' Teachers are now designers of learning experiences, tailored to accommodate needs, interests, and abilities [55-57].

2-2- International Evidence on GeoGebra Implementation

Internationally, studies present various patterns relating to GeoGebra implementation. Malaysian studies strongly suggest that training plays an important role in shaping teachers' intentions, including perceived ease of use and educational benefits [58]. Turkish studies suggest that GeoGebra has helped students shift from abstract to applied concepts, depending on factors such as class size and experience [59, 60]. In the African context, studies suggest that GeoGebra has assisted students in making abstract concepts fit into context, but class size and resources form barriers [61]. In Europe, studies focus on various types of teachers, ranging from non-users to GeoGebra content authors, suggesting that patterns of implementation success depend on development needs and institutional support [62, 63].

2-3- The Greek Educational Context: Unique Challenges

The Greek education system provides a distinct context for GeoGebra implementation, having introduced new educational frameworks that emphasize technological competencies. Challenges in finance, resulting from the economic crisis, affect support for resource allocation for professional development, leading to disparities in technology availability [51, 64]. The disparities in preparedness for technology integration, together with differences in professional development experience, result in inequities in preparedness [65, 66]. Although complex patterns of technology adoption and resistance have been revealed in previous Greek studies, ICT-based mathematics teaching is primarily implemented by well-qualified educators with higher education, underscoring the significant role of professional development [67, 68].

2-4- Technology Acceptance Model: Theoretical Foundation

This study is grounded in the Technology Acceptance Model (TAM), originally developed by Davis (1989), which has become one of the most influential frameworks for understanding technology adoption in educational contexts. TAM posits that two primary beliefs—Perceived Usefulness (PU) and Perceived Ease of Use (PEOU)—determine users' attitudes toward technology, which in turn influence behavioral intentions and actual use.

2-4-1- Rationale for TAM Selection in the Greek Context

TAM was selected for this study for three principal reasons specific to the Greek secondary education context:

First**,** TAM's focus on perceived barriers aligns with the Greek context, where implementation challenges are primarily structural rather than attitudinal. Preliminary evidence suggests Greek teachers recognize GeoGebra's value but face obstacles in translating positive attitudes into practice. TAM's constructs allow us to distinguish between teachers' recognition of GeoGebra's pedagogical value versus their assessment of implementation feasibility within institutional constraints.

Second**,** TAM has demonstrated cross-contextual validity across educational systems with varying levels of technological infrastructure, including studies in developing countries with comparable resource constraints [69, 70]. Meta-analyses report that TAM typically explains 40-50% of variance in technology usage intentions [50], providing a robust baseline for comparison.

Third**,** TAM's parsimony is advantageous for our survey-based methodology with a moderate sample size (N=82). More complex models would require larger samples for stable parameter estimation, potentially compromising statistical power.

2-4-2- Alternative Theoretical Models Considered

We acknowledge TAM's limitations, particularly its emphasis on individual-level factors at the expense of contextual influences. Several alternative models were considered:

The Unified Theory of Acceptance and Use of Technology (UTAUT) [71] extends TAM with additional constructs, including social influence and facilitating conditions. While UTAUT would provide richer contextual data, it requires substantially larger sample sizes to estimate its multiple moderating effects with sufficient precision, which exceeds the size of the accessible population in our target region.

The Technological Pedagogical Content Knowledge (TPACK) framework [72] would offer insights into how teachers integrate technological, pedagogical, and content knowledge. However, TPACK is better suited for qualitative or mixed-methods designs examining knowledge development rather than adoption patterns. The Concerns-Based Adoption Model (CBAM) [73] provides a developmental perspective on adoption stages but is primarily designed for longitudinal intervention studies rather than cross-sectional surveys.

To address TAM's individual-level limitations while maintaining methodological feasibility, we extend the traditional TAM framework by incorporating institutional factors (e.g., infrastructure availability, administrative support) and professional development variables (e.g., ICT certification levels). This extended model allows us to examine how systemic factors moderate the relationship between individual attitudes and actual usage.

3- Material and Methods

3-1- Research Design and Framework

This study employed a cross-sectional quantitative design, conducted between June and July 2023, to investigate the use of GeoGebra in secondary mathematics education. The research framework was based on the Technology Acceptance Model (TAM), conceptualized by Davis in 1986, providing a rich conceptual basis for understanding technology acceptance through four well-connected concepts: Perceived Usefulness, Perceived Ease of Use, Attitude Toward Use, and Actual Use of System.

3-2- Population and Sampling Procedures

The target population was all secondary mathematics teachers working in prefectures of Achaia and Aitoloakarnania in Western Greece. Both prefectures were chosen for their representative educational environments, including urban and rural schools with varying levels of technological support services. The number of secondary mathematics teachers was estimated at approximately 350, according to Ministry of Education data. Convenience sampling was adopted due to access constraints. Ultimately, 82 secondary mathematics teachers participated, representing an 87.7% response rate to the 94 questionnaires distributed.

3-2-1- Sampling Considerations and Potential Biases

The use of convenience sampling, while necessary given access constraints, introduces several potential biases that should be considered when interpreting findings:

Selection Bias: Teachers who voluntarily responded to the survey may be more interested in technology or more engaged in professional development than non-respondents. This positive selection could lead to overestimation of favorable attitudes toward GeoGebra and possibly underestimation of the implementation gap. The true implementation rates in the broader population may be even lower than those reported here.

Geographic Limitation: The sample is drawn exclusively from Western Greece (Achaia and Aitoloakarnania prefectures), which may not fully represent conditions in major urban centers (Athens, Thessaloniki) where infrastructure and professional development opportunities may be superior, or in remote island schools where resource constraints may be more severe.

Temporal Limitation: Data collection during summer months (June-July 2023) captured retrospective reflections on the completed academic year rather than in-the-moment assessments during active teaching. This timing may have affected recall accuracy.

Self-Report Limitations: Reliance on self-reported usage data may be affected by social desirability bias, with teachers potentially overreporting technology use to appear more innovative.

Mitigating Factors: Despite these limitations, the high response rate (87.7%) suggests strong engagement, and the demographic composition closely mirrors national statistics for Greek mathematics teachers, supporting reasonable generalizability for exploratory research purposes.

3-3- Instrumentation Development and Validation

The research instrument consisted of a structured questionnaire developed through a systematic review of relevant literature and adaptation of validated scales. The questionnaire was designed to capture both objective usage patterns and subjective perceptions regarding GeoGebra implementation, and was structured into three distinct sections to address different aspects of the research questions (see Table 1).

Table 1. **Questionnaire Structure and Measurement Scales**

Section	Focus Area	Items	Scale Type	Cronbach's α
Part I	Demographic Data	7	Categorical	N/A
Part II	Actual Use Assessment	4	5-point Likert	0.871
Part III	Usage Factors	14	5-point Likert	0.894
- Usefulness	Perceived Benefits	5	5-point Likert	0.881
- Ease of Use	Implementation Facilitators	7	5-point Likert	0.785
- Attitude	Personal Disposition	2	5-point Likert	0.805
Overall Scale	Complete Instrument	25	Mixed	0.925

The demographic section collected information on gender, age, educational qualifications, years of teaching experience, employment status, school type, and ICT training level. These variables were selected based on previous research identifying them as potential moderators of technology adoption in educational settings. The Actual Use Assessment section measured the frequency of GeoGebra implementation across four mathematical domains using a five-point Likert scale ranging from 1 (Not at all) to 5 (Very much). The domains assessed were Algebra, focusing on equation solving and function analysis; Geometry, encompassing constructions and transformations; Statistics, including data analysis and probability; and Analysis, covering calculus and advanced functions. The Usage Factors section refined the constructs from TAM using 14 questions, distributed across three subscales. The Usefulness subscale contained five questions to assess perceived benefits, including sparking students' interest, improving teaching skills, improving conceptual abilities, advancing exploration and experimentation, and enabling collaborative learning. The Ease of Use subscale contained seven questions to analyze factors that favor its integration, including ease of software use, facilitation of teaching, availability of infrastructure, institutional-level support, availability of ready-made materials, integration with the curriculum, and its ability to expedite or delay content coverage. The Attitude subscale contained two questions to assess personal preference for GeoGebra usage, perceived skills in GeoGebra usage, and interest in developing teaching scenes.

3-4- Data Collection Procedures

Data were collected via e-Distribution using Google Forms for accessibility and automatic compilation. Distribution was controlled to ensure ethical standards while maintaining participant anonymity. First contacts were made using official unit emails or direct communication with mathematics department heads. One reminder was distributed for non-respondents one week after the original emails. Participation took approximately ten minutes, established through pilot testing.

3-5- Statistical Analysis Procedures

Data analysis employed a comprehensive analytical strategy using SPSS version 27.0, with statistical significance set at $p < 0.05$ for all inferential tests. The analytical approach was designed to address each research question systematically while accounting for the non-normal distribution of variables identified through preliminary testing (see Table 2). Descriptive statistics were computed for all variables, including means, standard deviations, and frequency distributions. For interpreting Likert-scale responses, the following classification scheme was applied: scores from 1.00-1.79 were categorized as Very Low, 1.80-2.59 as Low, 2.60-3.39 as Moderate, 3.40-4.19 as High, and 4.20-5.00 as Very High. This categorization facilitated meaningful interpretation of usage patterns and factor ratings.

Table 2. **Statistical Analysis Strategy by Research Question**

Research Question	Primary Analysis	Secondary Analysis
RQ1: Usage Frequency	Descriptive Statistics	Frequency Distributions
RQ2: Influencing Factors	Mean Comparisons	Factor Ranking
RQ3: Demographic Effects	Mann-Whitney U, Kruskal-Wallis H	Post-hoc Comparisons
RQ4: School Type Effects	Kruskal-Wallis H	Mann-Whitney U (pairwise)
RQ5: Factor Relationships	Spearman's rho	Correlation Matrix
RQ6: Predictive Model	Linear Regression	Model Diagnostics

Kolmogorov-Smirnov normality tests indicated non-normality for all continuous variables ($p < 0.01$); therefore, non-parametric statistical analyses were required. For between-group comparisons, the Mann-Whitney U test was used for pairwise comparisons (e.g., gender and employment status), while the Kruskal-Wallis H test was used for comparisons involving more than two groups (e.g., age groups, education levels, and years of experience). For correlation analyses, Spearman's rho was used to examine relationships between ordinal and continuous variables. The correlation coefficients are non-parametric and tolerant to non-normal data distribution. For post-hoc analyses to identify which pairs are significantly different for variables that employed the Kruskal-Wallis H test, pairwise comparisons using the Mann-Whitney U test with Bonferroni correction for Type I error inflation are applied. To answer RQ6, hierarchical regression analyses are employed for explanatory research, despite non-normal data distributions, provided the sample size is sufficient. Residual checks are applied to ensure that every assumption for regression analyses is well satisfied.

3-6- Limitations of Methodology

Some methodological constraints must be considered when analyzing the implications of this research. The convenience sampling methodological design, although convenient, does restrict generalization to Greek mathematics educators. The geographical focus on only two prefectures in Western Greece might not capture regional disparities elsewhere in the country, including major cities and isolated areas. A cross-sectional design allows for evaluation but only offers a point-in-time snapshot and does not permit evaluation of cause-and-effect or patterns that emerge over time. Social desirability bias can affect reliance on self-report data, leading individual educators to exaggerate their technology use. The lack of classroom observations or outcomes prevents verification or evaluation of the success of the practice. Overreliance on quantitative research methodologies may overlook subtle complexities in implementation difficulties and successes that can be uncovered through qualitative research methodologies. Future studies using mixed-methods research designs could be informative for making sense of complex variables affecting GeoGebra usage in secondary education mathematics.

4- Results

The study sample comprised 82 secondary school mathematics teachers from the prefectures of Achaia and Aitoloakarnania, Greece, representing an 87.7% response rate from the 94 questionnaires distributed during June-July 2023. This high response rate suggests strong engagement with the research topic and minimal non-response bias within the accessible population (see Table 3).

Table 3. Sociodemographic Characteristics of the Study Sample (N = 82)

Characteristic	Category	n	%	Cumulative (%)
Gender	Male	36	43.9	43.9
	Female	46	56.1	100.0
Age Group (years)	≤30	1	1.2	1.2
	31-40	11	13.4	14.6
	41-50	33	40.2	54.8
	≥51	37	45.1	100.0
Educational Attainment	Basic degree	23	28.0	28.0
	Second degree	1	1.2	29.2
	Master's degree	55	67.1	96.3
	Doctorate	3	3.7	100.0
Teaching Experience (years)	0-5	13	15.9	15.9
	6-10	10	12.2	28.1
	11-20	35	42.7	70.8
	≥21	24	29.3	100.0
Employment Status	Permanent	69	84.1	84.1
	Substitute	13	15.9	100.0
School Type	Gymnasium (Lower Secondary)	30	36.6	36.6
	General Lyceum (Upper Secondary)	41	50.0	86.6
	EPAL (Technical)	8	9.8	96.4
	ENEGYL (Evening)	3	3.7	100.0
ICT Training Level	None	16	19.5	19.5
	A Level	14	17.1	36.6
	B1 Level	16	19.5	56.1
	B2 Level	36	43.9	100.0

The gender representation aligned with the expected predominance of females in the profession (56.1%), a pattern prevalent in education. The representation by participants' ages showed a mature labor force, with 85.3% aged 40 or older and only 1 aged below 30, reflecting delayed entry into the workforce, which is common in the Greek education system. The level of education attained was very advanced, with 67.1% holding Master's degrees and 3.7% holding doctoral degrees, reflecting advanced education among mathematical teachers. The percentage for permanent personnel (84.1%) indicates a relatively stable labor force, while 15.9% for replacement personnel suggests labor challenges in Greek education. Needs for professional development in ICT showed promising trends, with 43.9% attaining B2 certification, the highest level within the framework. Nevertheless, 19.5% reported no ICT education, indicating significant development needs in education. Classification by school type reflected the Greek education structure, with half of the participants working in General Lyceums, followed by Gymnasiums for more than one-third, and, finally, schools for specific subjects (EPAL and ENEGYL), accounting for 13.5% of participants.

4-1- GeoGebra Usage Patterns Across Mathematical Domains (Research Question 1)

The first research question examined the frequency of GeoGebra use in mathematics teaching scenarios, assessed through Part Two of the questionnaire measuring actual use across four mathematical domains. Table 4 presents the interpretation scale for mean scores, derived by dividing the 1-5 response range into five equal intervals.

Table 4. Interpretation Scale for Mean Scores

Score Range	Interpretation
1.00 - 1.79	Very Low
1.80 - 2.59	Low
2.60 - 3.39	Moderate
3.40 - 4.19	High
4.20 - 5.00	Very High

Analysis revealed generally low implementation levels across all mathematical domains, with significant variation in usage patterns. The overall mean usage score was 2.21, indicating a low frequency of GeoGebra implementation in secondary mathematics education (Table 5).

Table 5. Descriptive Statistics for GeoGebra Usage by Mathematical Domain (N = 82)

Domain	M	SD	Min	Max	Skewness	SE	95% CI	Interpretation
Geometry	2.77	1.092	1	5	0.42	0.121	[2.53, 3.01]	Moderate
Algebra	2.32	0.980	1	5	0.89	0.108	[2.10, 2.54]	Low
Analysis	1.98	1.122	1	5	1.23	0.124	[1.73, 2.23]	Low
Statistics	1.77	0.998	1	5	1.56	0.110	[1.55, 1.99]	Very Low
Overall	2.21	0.910	1	5	0.78	0.100	[2.01, 2.41]	Low

Note. SE = Standard Error; CI = Confidence Interval.

Geometry demonstrated the highest implementation rate (M = 2.77, SD = 1.092), achieving moderate usage levels and approaching the 2.60 threshold. This preferential adoption in Geometry aligns with the software's visual-dynamic capabilities that naturally complement geometric exploration. Algebra showed intermediate implementation (M = 2.32, SD = 0.980), while Analysis (M = 1.98, SD = 1.122) and Statistics (M = 1.77, SD = 0.998) demonstrated particularly low adoption rates, with Statistics falling into the very low category (Table 6).

Table 6. Frequency Distribution of GeoGebra Usage Levels Across Mathematical Domains

Usage Level	Algebra		Geometry		Statistics		Analysis	
	n	%	n	%	n	%	n	%
Not at all (1)	18	22.0	10	12.2	44	53.7	38	46.3
A little (2)	30	36.6	25	30.5	20	24.4	20	24.4
Quite a lot (3)	26	31.7	26	31.7	12	14.6	14	17.1
Much (4)	6	7.3	16	19.5	5	6.1	8	9.8
Very much (5)	2	2.4	5	6.1	1	1.2	2	2.4
High Usage (4-5)	8	9.7	21	25.6	6	7.3	10	12.2

The frequency distribution reveals concerning patterns, particularly in Statistics where 53.7% of teachers report no usage whatsoever, and an additional 24.4% report minimal engagement. Only 7.3% achieve substantial implementation in Statistics. Analysis shows similar patterns with 46.3% reporting no use. Conversely, Geometry demonstrates more encouraging adoption, with only 12.2% reporting no use and 25.6% achieving high implementation levels (ratings of 4 or 5).

4-2- Factors Influencing GeoGebra Implementation (Research Question 2)

The second research question investigated factors influencing GeoGebra use through the Technology Acceptance Model framework, assessed via Part Three of the questionnaire comprising 14 items across three constructs: Perceived Usefulness (5 items), Perceived Ease of Use (7 items), and Attitude Toward Use (2 items).

The hierarchy of influencing factors places Attitude Toward Use as the most important determinant (M = 3.53, SD = 1.073), followed closely by Perceived Usefulness (M = 3.42, SD = 0.930), both of which achieve high ratings. Perceived Ease of Use showed a moderate influence (M = 2.97, SD = 1.085), with practical implementation challenges identified as the primary constraint (Table 7).

Table 7. Descriptive Statistics and Reliability for TAM Constructs (N = 82)

Construct	M	SD	Median	IQR	Min	Max	Cronbach's α	Interpretation
Attitude Toward Use	3.53	1.073	3.50	1.50	1	5	0.805	High
Perceived Usefulness	3.42	0.930	3.40	1.20	1	5	0.881	High
Perceived Ease of Use	2.97	1.085	3.00	1.43	1	5	0.785	Moderate
Overall TAM Factors	3.31	1.079	3.30	1.38	1	5	0.894	Moderate

Note. IQR = Interquartile Range. All scales demonstrated acceptable reliability (α > 0.70).

Within the Perceived Usefulness dimension, conceptual understanding emerged as the highest-rated benefit (M = 3.52), followed by promotion of experimentation (M = 3.46) and student interest (M = 3.46). The lower rating for collaborative learning enhancement (M = 3.27) suggests that teachers perceive challenges in facilitating group work with the software (Table 8).

Table 8. Item-Level Analysis of Perceived Usefulness Subscale (N = 82)

Item	M	SD	Min	Max	Item-Total r
Helps students understand mathematical concepts	3.52	0.984	2	5	0.742
Promotes experimentation and exploration	3.46	0.905	2	5	0.718
Increases student interest	3.46	0.950	1	5	0.695
Makes teaching more effective	3.38	0.925	2	5	0.683
Enhances collaborative learning	3.27	0.876	1	5	0.654
Subscale Total	**3.42**	**0.930**			

The Ease-of-Use analysis reveals critical implementation barriers. While the software itself is perceived as facilitating teaching (M = 3.46) and relatively user-friendly (M = 3.32), institutional factors present significant obstacles. Technical infrastructure (M = 2.62) and school encouragement (M = 2.56) fall below the moderate threshold, identifying systemic barriers to implementation (Table 9).

Table 9. Item-Level Analysis of Perceived Ease of Use Subscale (N = 82)

Item	M	SD	Min	Max	Item-Total r
Software facilitates teaching	3.46	0.958	2	5	0.689
Software is easy to use	3.32	0.954	1	5	0.672
Ready-made materials available	3.15	1.101	1	5	0.598
Curriculum provides guidance	2.88	0.990	1	5	0.567
*Slows content coverage (reversed)	2.79	1.108	1	5	0.542
Technical infrastructure available	2.62	1.240	1	5	0.521
School provides encouragement	2.56	1.228	1	5	0.508
Subscale Total	**2.97**	**1.085**			

Note. Item marked with asterisk was reverse-coded before analysis.

Teachers express both interest in creating GeoGebra scenarios (M = 3.55) and confidence in their abilities (M = 3.51), with minimal difference between motivational and competency aspects (Table 10).

Table 10. Item-Level Analysis of Attitude Toward Use Subscale (N = 82)

Item	M	SD	Min	Max	Item-Total r
Interest in creating/modifying scenarios	3.55	1.044	1	5	0.672
Have necessary skills and knowledge	3.51	1.100	1	5	0.672
Subscale Total	**3.53**	**1.073**			

4-3- Sociodemographic Influences on Implementation (Research Question 3)

The third research question examined relationships between GeoGebra usage and sociodemographic factors. Preliminary Kolmogorov-Smirnov tests confirmed non-normal distributions for all continuous variables (all $p < 0.01$), necessitating non-parametric analytical approaches.

Gender differences emerged selectively, with statistically significant disparities only in Analysis courses ($U = 581.00$, $z = -2.45$, $p = 0.014$, $r = 0.27$), where males demonstrated higher implementation. This domain-specific effect, absent in other mathematical areas, suggests contextual rather than general gender influences on technology adoption (Table 11).

Table 11. Gender Differences in GeoGebra Usage (Mann-Whitney U Test)

Domain	Male (n=36)		Female (n=46)					
	Mean Rank	M(SD)	Mean Rank	M(SD)	U	z	p	r
Analysis	48.36	2.31(1.17)	36.13	1.72(1.03)	581.00	-2.45	0.014*	0.27
Algebra	44.28	2.47(1.03)	39.52	2.20(0.95)	712.00	-1.07	0.285	0.12
Geometry	43.14	2.86(1.13)	40.23	2.70(1.07)	753.00	-0.66	0.512	0.07
Statistics	42.89	1.86(1.07)	40.43	1.70(0.94)	762.00	-0.56	0.577	0.06

Note. r = effect size ($z/\sqrt{N}$). *$p < 0.05$.

ICT training emerged as a critical determinant, with B2-level certification showing dramatic effects on implementation (Table 12). Post-hoc pairwise comparisons using Mann-Whitney U tests with Bonferroni correction confirmed that B2-trained teachers significantly exceeded all other groups in both Algebra and Analysis (all adjusted $p < .05$).

Table 12. ICT Training Level Effects on GeoGebra Usage (Kruskal-Wallis H Test)

Domain	Training Level	n	Mean Rank	M(SD)	H	df	p	η²
Algebra					9.549	3	0.023*	0.094
	None	16	33.75	1.94(0.85)				
	A Level	14	32.64	2.00(0.88)				
	B1 Level	16	37.75	2.19(0.91)				
	B2 Level	36	50.06	2.64(1.02)				
Analysis					15.103	3	0.002**	0.153
	None	16	33.50	1.50(0.82)				
	A Level	14	33.07	1.57(0.85)				
	B1 Level	16	32.50	1.56(0.89)				
	B2 Level	36	52.33	2.53(1.21)				

Note. η^2 = effect size ($H/(N-1)$). *$p < 0.05$, **$p < 0.01$.

The curvilinear relationship with experience reveals that teachers with 6-10 years demonstrate peak implementation (Mean Rank = 51.10), significantly exceeding novices (0-5 years) but showing comparable usage to veterans (≥21 years) (Table 13).

Table 13. **Teaching Experience Effects on GeoGebra Usage in Algebra**

Experience (years)	n	Mean Rank	M(SD)	Pairwise Comparisons
0-5	13	26.42	1.85(0.80)	
6-10	10	51.10	2.70(0.95)	> 0-5**
11-20	35	39.21	2.29(0.96)	
≥21	24	49.00	2.54(1.10)	> 0-5*

Note. Kruskal-Wallis $H(3) = 10.501$, $p = .015$. *$p < .05$, **$p < .01$ for pairwise comparisons.

4-4- Institutional Context Effects (Research Question 4)

The fourth research question examined school-type variations in GeoGebra implementation for Algebra and Geometry, the two subjects taught across all secondary levels. No statistically significant differences emerged across school types for either Algebra ($H(3) = 2.397$, $p = 0.495$) or Geometry ($H(3) = 0.128$, $p = 0.985$), suggesting that implementation challenges transcend institutional contexts (Table 14).

Table 14. **School Type Effects on GeoGebra Usage (Kruskal-Wallis H Test)**

Domain	School Type	n	M(SD)	Mean Rank	H	df	p
Algebra	Gymnasium	30	2.23(0.94)	38.65	2.397	3	0.495
	General Lyceum	41	2.41(1.02)	43.88			
	EPAL	8	2.13(0.83)	35.50			
	ENEGYL	3	2.67(1.53)	48.67			
Geometry	Gymnasium	30	2.73(1.08)	40.85	0.128	3	0.985
	General Lyceum	41	2.78(1.11)	41.51			
	EPAL	8	2.88(1.13)	43.88			
	ENEGYL	3	2.67(1.53)	39.00			

4-5- Predictive Model Development (Research Question 6)

The fifth research question examined interrelationships among TAM constructs using Spearman's rank correlation due to non-normal distributions. Strong positive correlations emerged among all constructs, with the strongest relationship between Attitude Toward Use and Ease of Use ($r_s = 0.701$, $p < 0.001$), suggesting that the feasibility of practical implementation strongly influences teacher attitudes. The correlation between Actual Use and Attitude ($r_s = .580$) exceeds that between Usefulness and Attitude ($r_s = 0.512$), indicating that disposition toward technology may be more predictive of implementation than recognition of benefits (Table 15).

Table 15. **Spearman Correlation Matrix for TAM Constructs and Actual Use (N = 82)**

Variable	1	2	3	4
1. Actual Use	—			
2. Perceived Usefulness	0.512** [0.341, 0.651]	—		
3. Perceived Ease of Use	0.572** [0.412, 0.698]	0.690** [0.562, 0.787]	—	
4. Attitude Toward Use	0.580** [0.421, 0.704]	0.665** [0.531, 0.769]	0.701** [0.576, 0.795]	—

Note. Values in brackets represent 95% confidence intervals. **$p < 0.01$ (two-tailed).

4-6- Predictive Model Development (Research Question 6)

The sixth research question sought to develop a predictive model for actual GeoGebra use based on TAM constructs using hierarchical linear regression. The regression model explained 40.1% of the variance in actual use ($R^2 = 0.401$, $F(3,78) = 17.374$, $p < 0.001$). Perceived Ease of Use ($\beta = 0.360$, $p = 0.044$) and Attitude Toward Use ($\beta = 0.281$, $p = 0.018$) emerged as significant predictors, while Perceived Usefulness did not reach significance ($\beta = 0.127$, $p = 0.319$). VIF values below 2.5 indicate no multicollinearity concerns. The Durbin-Watson statistic of 1.92 suggests independence of residuals (Table 16).

Table 16. **Hierarchical Regression Analysis Predicting Actual GeoGebra Use**

Predictor	B	SE	β	t	p	95% CI	VIF
Model Statistics: $R^2 = 0.401$, Adjusted $R^2 = 0.378$, $F(3,78) = 17.374$, $p < 0.001$							
Constant	-0.360	0.386	—	-0.932	0.354	[-1.129, 0.409]	—
Perceived Usefulness	0.148	0.147	0.127	1.003	0.319	[-0.145, 0.441]	2.14
Perceived Ease of Use	0.360	0.176	0.360	2.044	0.044*	[0.009, 0.711]	2.31
Attitude Toward Use	0.281	0.116	0.281	2.419	0.018*	[0.050, 0.512]	2.08

Note. SE = Standard Error; CI = Confidence Interval; VIF = Variance Inflation Factor. *$p < 0.05$.

The final predictive equation: Actual Use = -0.36 + 0.36(Ease of Use) + 0.28(Attitude Toward Use)

This model indicates that each unit increase in Perceived Ease of Use predicts a 0.36-unit increase in actual usage, while each unit increase in Attitude corresponds to a 0.28-unit increase, holding other factors constant (Table 17).

Table 17. **Model Diagnostics and Assumptions Testing**

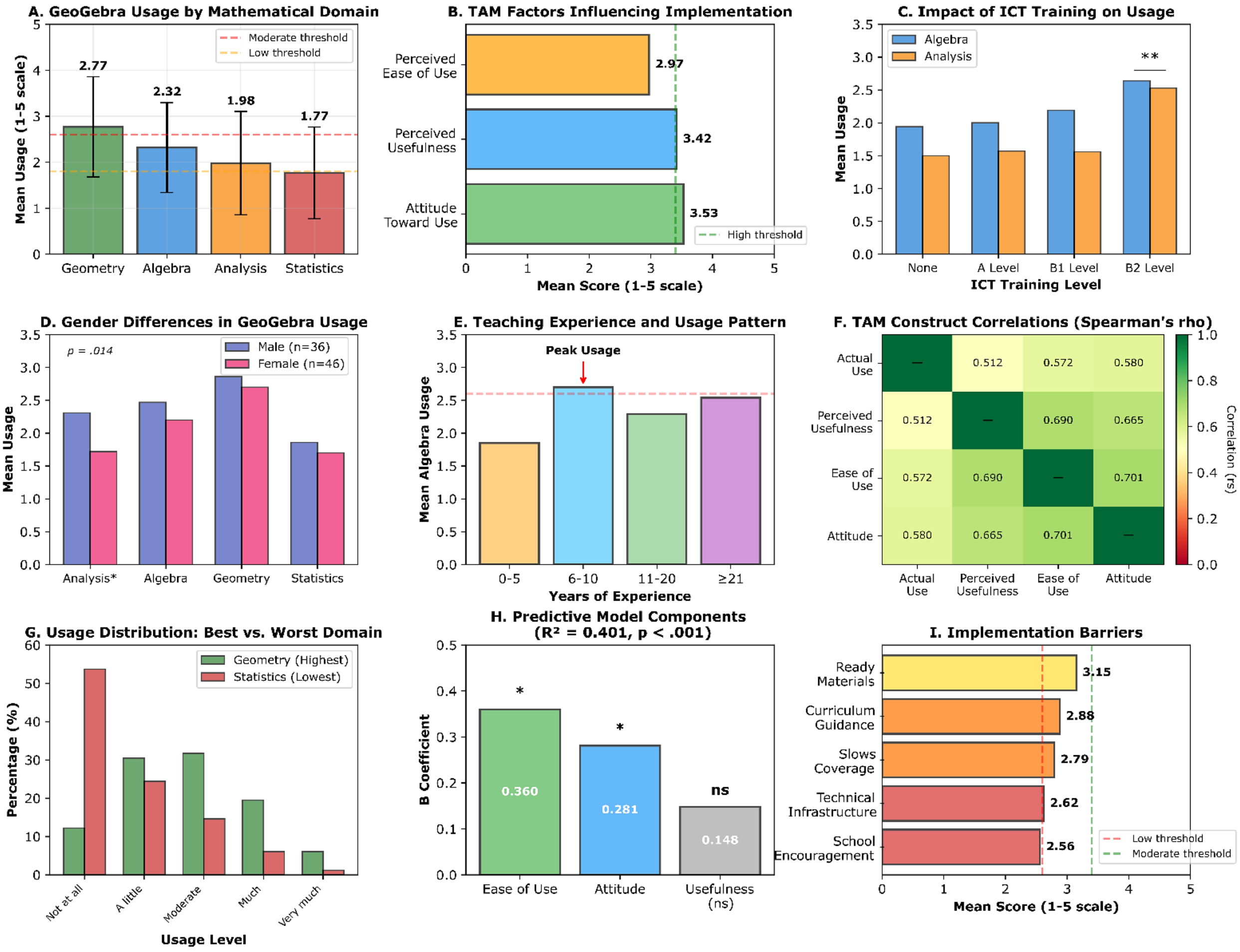
Diagnostic Test	Statistic	p-value	Interpretation
Kolmogorov-Smirnov (residuals)	0.074	0.200	Normal distribution
Breusch-Pagan	2.891	0.409	Homoscedasticity confirmed
Durbin-Watson	1.924	—	Independence confirmed
Maximum VIF	2.31	—	No multicollinearity
Cook's Distance (max)	0.082	—	No influential outliers

All regression assumptions were satisfied, supporting the validity of the predictive model. The non-significance of Perceived Usefulness in the presence of other predictors suggests that while teachers recognize GeoGebra's value, practical barriers and attitudes more directly determine implementation.

4-7-Summary of Key Findings

The integrated analysis provides insight into a complex implementation environment where overall usage remains very low (M = 2.21), in contrast to moderately favorable attitudes (M = 3.53) and perceived usefulness (M = 3.42) perceptions. The degree to which each domain has been implemented varies from moderately to very low, with Geometry at M = 2.77 and Statistics at M = 1.77. Furthermore, the Technology Acceptance Model Analysis identifies Attitude Towards Use as the most important factor, followed by Usefulness, while Perceived Ease of Use, with moderate usage, lags, highlighting technological difficulties as important barriers to overcome. Professional development factors prove to be important, with B2-level certification resulting in dramatically higher usage for the Algebra domain by factor M = 2.64 than other certification levels (Algebra: 1.94-2.19), and the Analysis domain usage rises to M = 2.53 compared to other certification levels (Analysis: 1.50-1.57). Moreover, it appears that implementing technology requires comprehensive development to demonstrate its added value. Gender gaps emerge only for the Analysis domain, while experience varies in a curve, ranging from 6 to 10 years, to identify optimal technology implementation periods. Infrastructure factors rank as important barriers to technology implementation in Greek secondary mathematics education, with infrastructural support for technology use remaining at very low levels (M = 2.62), while Support from the School remains slightly above very low (M = 2.56). The technology usage function successfully explains 40.1% of the variance using the factors ‘Ease of Use’ and ‘Attitude Towards Use’, while ‘Usefulness’ remains non-significant, indicating perceived usefulness but insufficient support for its practical implementation.

Figure 1 encapsulates key research observations from various inquiries into a domain-specific mosaic of usage patterns, the hierarchy of Technology Acceptance Model factors, demographic factors, and predictive associations identified in this research. It depicts: (A) usage means for mathematical domains for moderate (2.6) and low (1.8) usage threshold levels, where Geometry scored moderately well (M=2.77) but Statistics scored very poorly (M=1.77); (B) hierarchy for Technology Acceptance Model factors, where Attitude Toward Use emerged as leader at 3.53, followed by perceived Usefulness at 3.42, and perceived Ease of Use at 2.97 points; (C) ICT training factors, where B2 certification emerged as critical usage threshold for implementation success; (D) gender disparities, where Analysis usage existed as only significant gender difference with p-value .014; (E) curvilinear relations showing usage peaked at 6-10 years for experienced teachers; (F) correlation matrix using Spearman correlation analysis, showing very strong linkages between various factors of Technology Acceptance Model with correlation coefficients ranging between .512 to .701; (G) distribution comparisons pointing to gargantuan non-implementation ratio between Geometry (12.2%) and Statistics (53.7%); (H) regression analysis highlighting important elements in usage model, including R^2= .401 probability with p-value .0001, where only Ease of Use (B= 0.360) and Attitude Towards Use (B= 0.281) factors are significant; and finally, revealing critical factors for non-implementation at Infrastructure (2.62) and Support factors at 2.56 points below moderate threshold level. Error bars shown are ± SD. Significance levels: * p-value 0.05, ** p-value 0.01, ns=not significant.



*Note: Error bars represent ±1 SD. Significance levels: *p < .05, **p < .01, ns = not significant.*
Scale interpretation: 1.00-1.79 = Very Low, 1.80-2.59 = Low, 2.60-3.39 = Moderate, 3.40-4.19 = High, 4.20-5.00 = Very High.

Figure 1. **Comprehensive analysis of GeoGebra implementation in secondary mathematics education (N = 82)**

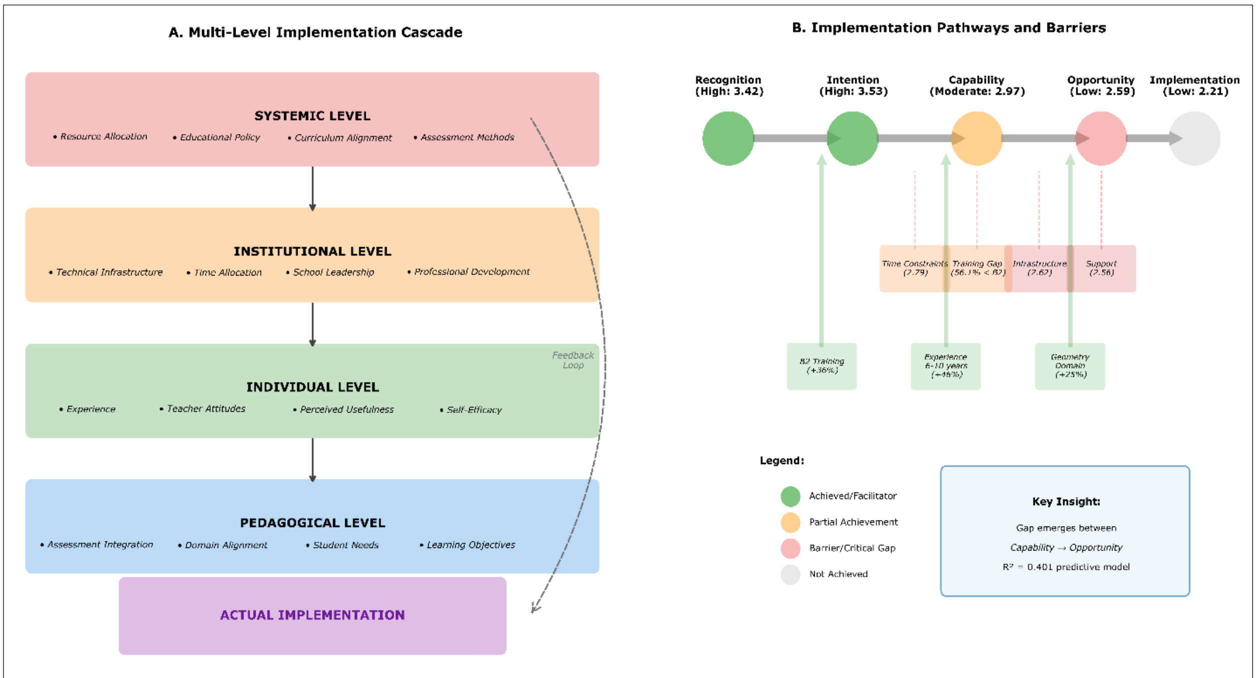
5- Discussion

5-1- Synthesis of Principal Findings

This large body of research on GeoGebra implementation in Greek secondary education mathematics highlights a significant paradox in how technology implementation is defined in resource-limited educational environments. The identified level of implementation, 2.21 on the five-level scale, with faculty sentiment at 3.53 and perceived usefulness at 3.42, addresses "the implementation-intention gap" in educational innovation. This phenomenon not only underscores the failure of technology implementation but also addresses it by showing how aspirations are disconnected from reality in Greek education. The existence of domain variation in terms of implementation, where Geometry has moderate implementation with 2.77, in contrast to Statistics' 1.77, provides very important data on how technology implementation for mathematics education functions. This not only addresses preferences but also certain elements of underlying epistemological ideologies regarding how areas of mathematics are defined within technology. For instance, Geometry has its own connections to GeoGebra regarding how visuals and space work, and GeoGebra can be applied very easily by mathematics teachers to explain transformations and properties. Statistics and Analysis, on the other hand, are abstract and procedural areas within mathematics, using GeoGebra technology capabilities, which are implemented to a very large extent poorly, adding to other cognitive barriers to technology implementation.

5-2- Theoretical Implications and Framework Development

The findings necessitate an expanded theoretical framework that extends beyond the traditional Technology Acceptance Model to encompass the unique complexities of educational technology adoption in secondary mathematics. Based on our empirical evidence, we propose the Contextual Implementation Cascade Framework (CICF) to understand GeoGebra adoption, conceptualizing implementation as a multi-level process influenced by individual, institutional, and systemic factors. The CICF framework, illustrated in Figure 2, reveals that successful implementation requires alignment across four interconnected levels.



Note: Framework based on empirical findings from N=82 secondary mathematics teachers. Values in parentheses represent mean scores or percentages from the study.

Figure 2. **Contextual Implementation Cascade Framework (CICF) for GeoGebra Adoption**

Panel A shows how the multi-level cascade begins from systemic to pedagogical factors for implementation. Panel B shows how implementation can progress from recognition to actual use, highlighting key barriers and facilitators based on empirically supported research. For systemic factors, education policy structure, curriculum structure, and assessment design form the top-down environment that can either support or hinder technology integration. Then come the institutional-level factors, which involve the immediate environmental context within which organizations operate, including technology structure, leadership support, and professional development opportunities. Next are individual factors, in which attitudes, efficacy, and experience of individual teachers are classified. After that are pedagogical factors, in which technological tools are considered in relation to mathematical content areas. The data extracted from our research aligns with this framework, showing that, though individual factors provide promising signs with high scores on attitudes and perceived usefulness, their breakdown occurs at the institutional-level factors, where scores on technology structure are only 2.62 and support factors are only 2.56. This explains why promising individual dispositions are not actualized in class. The feedback loop brought about by this framework, depicted by the dotted box line, illustrates how insufficient implementation experience can hinder the confidence and skills needed to overcome institutional barriers, thereby forming a cycle of non-adoption.

5-3- The Professional Development Threshold Effect

The dramatic disparity between B2-certified educators and other educators with lower or no certification is perhaps one of the most treatable discoveries within this research. B2-certified educators are predicted to achieve usage rates of 2.64 in Algebra and 2.53 in Analysis, compared to non-certified or lower-certified rates of 1.50-2.00, making this threshold fully representative of professional development as something entirely other than a linear function, but rather something distinctly quantifiable. This threshold can be accurately qualified within the construct of technological pedagogical content knowledge, inasmuch as B2 certification is essentially representative of something only slightly above the minimum for effectively integrating content at every level. Anything below is representative of technological or conceptual familiarity but does not provide well-integrated skills for seamless technological integration. This has implications not only within professional development but perhaps for anything indicative or representative of education or intellectual capital acquisition, inasmuch as anything but full or substantial development is absolutely and literally no development at all—a rather bleak assessment for education informatics as representative within preference for shallow but universal development rather than deep but concise development. This discovery that 56.1% of educators did not provide B2 certification is indicative of a monumental development disparity, perhaps most directly within our own control to address, perhaps most immediately, certainly far faster than restrictions imposed by technological or development needs. Additionally, within this threshold, a development opportunity must provide B2 development rather than shallow familiarity.

5-4- Gender and Experience Dynamics

The selective manifestation of gender differences only within Analysis lessons, where males tend to show higher levels of implementation, certainly requires subtle analysis to avoid simplistic generalizations. This context-dependent phenomenon reveals that gender differences in technology adoption are complexly entangled with mathematical content, rather than reflecting general technological preference or aversion. The issue of Analysis within Greek secondary education essentially involves complex concepts of calculus, limit definitions, and derivatives, which may relate to gender differences in mathematical confidence as reported in existing research studies. That gender gaps are eliminated in Geometry, Algebra, and Statistics means that where mathematics is well modeled with visually dynamic representations or involves more concrete manipulatives, gender inequities in technology use are eliminated or reduced to insignificance. This suggests that support for female educators in Analysis lessons, perhaps through gender-specific personnel development to address confidence or skill deficits in advanced mathematical software, can eliminate or reduce this inequity. The nonlinear nature of experience and implementation, peaking between 6-10 years, reveals that technology adoption has its critical period for implementation that contradicts technology nativism and experience-driven competency notions. Beginning educators, perhaps more familiar with technology, will implement at lower rates, perhaps experiencing cognitive overload as they simultaneously cope with basic education dilemmas introduced by technology integration. Seasoned educators, perhaps with many more years of experience, implement in moderation, perhaps reflecting deeply ingrained teaching habits resistant to change or previous technology failures that soured them on new ideas. The 6-10-year phase is when experience and confidence in education, tolerance for change, and energy reserves are at their optimal levels, which can be tapped for leadership development within educational institutions.

5-5- Infrastructure and Institutional Barriers

The emergence of technical infrastructure and encouragement from schools as essential barriers to overcome, with scores below the moderate level, point to various failures in the system that no motivational factor can surmount. This mixture of discoveries aligns with global studies showing that, for integrated technology to flourish in education, as described by Zhao & Feng [70], "ecological" harmony between technology and all other elements is essential. It is especially alarming to see that in 2023, with a score of 2.62 in a country that is also a member state of the European Union, basic technological requirements are still not met in many schools in Greece. This technological requirement is not only a problem but also a psychological issue for many Greek educators, since they are unlikely to work with GeoGebra resources when they know that access to proper computers is not guaranteed. The relatively low score for support for education at 2.56 indicates that the culture within institutions does not support or promote technology integration, but rather allows it to happen. This aspect of culture can prove challenging, as it affects various factors simultaneously, including the allocation of time for experimentation, collaboration, rewards for innovative practices, and the acceptance that will inevitably occur in the course of introducing new ideas into education. Lack of support within institutions generates what we could describe as “innovation isolation,” where individual educators are tasked with implementing GeoGebra in addition to overcoming technological and educational hurdles, while also encountering institutional resistance to change.

5-6- Infrastructure and Institutional Barriers

The implementation paradox observed in this research, in which perceived value does not lead to implementation, can now be explained by various factors emerging from our analysis. Teachers are able to overcome initial barriers related to awareness and attitude formation, as shown by positive scores for usefulness and attitudes. However, they are simultaneously confronted with various barriers at the point where action must follow intention. The moderate ease-of-use score of 2.97 reveals that, though they hold favorable attitudes, they encounter many practical difficulties in its implementation. These difficulties are further multiplied by various institutional impediments pertaining to infrastructural support and the need for advanced training. The model predicts how well it performs, explaining 40.1% of the variance through ease of use and Attitude, though Usefulness is non-significant, implying that the battle for hearts and minds has been won. However, the implementation difficulties remain unaddressed. This paradox illustrates the larger issue in educational innovation, whereby innovations are disproportionately concerned with raising awareness and shifting attitudes but pay little heed to the more prosaic but equally important elements within implementation support. The finding that perceived usefulness does not strongly contribute to actual usage, even after controlling for ease of use and attitude, suggests that no further attempts to persuade educators of GeoGebra's usefulness in education are warranted, but rather efforts to reduce hurdles to its implementation within institutions.

5-7- Infrastructure and Institutional Barriers

Our results both support and contrast with global trends in important ways. The general difficulty in implementation can be seen as part of broader issues in educational technology adoption, where, despite significant investment and effort, classroom adoption has remained relatively limited. The pattern of barriers and facilitators, however, has its own set of characteristics within the Greek context. The threshold effect of B2-level training seems more pronounced than in other studies in Northern European countries, where basic digital literacy skills are already widespread and infrastructural support is better. This indicates that in more challenging contexts, professional development needs to reach higher levels to overcome environmental barriers. The gender effect is observed only in the analysis and does not align with global patterns of technology adoption, which appear to exhibit larger gender gaps between males and females, perhaps indicative of Greece's relatively equal society in education, where women dominate the teaching force. The pattern observed for curvilinear experience has been replicated in other global settings, supporting that it is indicative of a general phenomenon that crosses boundaries of culture and context. This finding supports further efforts to target professional development for mid-career educators when optimal levels of adoption readiness are met.

5-8- Implications for Practice and Policy

This body of empirical data provides precise recommendations for various stakeholders. First, for education policymakers, it is essential to prioritize employee development to ensure B2-level certification among mathematics educators. Indeed, 56.1% of mathematics educators can benefit from this minimum criterion rather than treating it as a noble aim. Infrastructure investment also has to involve more than just providing computer access and has to focus on ensuring the availability and maintenance of computer systems and relevant software support. That previous investments in computing infrastructure haven't reduced inadequacy to primarily a barrier at this point in 2023 is implied by its continued existence. Infrastructure investments must factor sustainability into their approach to improve on previous strategies. School leaders need to develop cultures for GeoGebra implementation through concrete interventions, such as setting aside time for GeoGebra experimentation, providing space for collaboration and sharing experiences, establishing reward frameworks that honor innovations in education, and tolerating or accepting reduced efficiency during technology integration. The relatively low score under institutional support within GeoGebra implementation warrants active support rather than acceptance or tolerance. For classroom teachers, implications for GeoGebra adoption include strategic ways for its adoption. Starting with Geometry, where barriers to implementation are minimal, and chances for success are high, can develop skills that can be applied elsewhere. To overcome a lack of institutional support, obtaining or mobilizing support from peers can help fill gaps. Support for B2-level training, on grounds of its empirically proven effectiveness, can secure resources.

5-9- The Domain-Specific Challenge

The great disparity in the degree to which each mathematical field has implemented technology integration, from Geometry's success to Statistics' limited integration, necessitates subject-specific approaches rather than general technology integration strategies. The visually dynamic nature of geometric ideas provides natural affordances in GeoGebra's interface, making it relatively straightforward for instructors to depict ideas that would be very challenging or, in essence, impossible to illustrate with static technology. The low score for Statistics, despite GeoGebra's strong statistical capabilities, suggests that other factors are also working against classroom implementation in this subject. The peripheral nature of Statistics education in Greek secondary mathematics education, typically covered in a rush near the end of the year, creates ample opportunities for structural impediments to technological integration. Moreover, Statistics education necessitates methodological practices distinct from those in ordinary mathematics education, which can introduce dual implementation difficulties. Analysis falls in between, where implementation is hampered by the abstract nature of the analysis, as well as by calculus concepts and the identified gender factor. The cognitive rigor involved in teaching limits, derivatives, or integration can cause cognitive overload, making it difficult to implement technology at the same time. The development of domain-specific support resources and implementation documents can mitigate differential factors.

5-10- Methodological Contributions and Limitations

Despite this, certain limitations hinder generalization to varying degrees. Because it is cross-sectional, it does not support inferential analyses of whether its implementation has a lagged or direct relationship with perceptions, or vice versa. Moreover, the convenience sampling method using data from two Western prefectures in Greece may introduce biases in the representativeness of Greek data, particularly for larger cities and remote Greek islands. Certain biases exist in reported usage patterns, but it appears to hold negligible data. Omissions in classroom data hinder analyses of actual implementation quality rather than just frequency. The data-gathering approach for summer sessions can also introduce response bias, as teaching faculty, after finishing one academic session, provide varied responses to queries compared to those they provide during sessions. Secondly, GeoGebra has remained under its firm control as a research focus, providing in-depth control. Moreover, this research could not draw clear conclusions or generalize well about technology integration sessions in education to varying degrees.

5-11- Future Research Directions

The implications offer various avenues for further study to deepen understanding and develop evidence-based interventions. Longitudinal research on teachers, from teacher education to B2 Certification and on to personal growth stages, can provide important support points and specify cause-and-effect relationships among education, beliefs, and practices [74-77]. Experimental studies on intervention for defined approaches to teacher development, infrastructural arrangements, and support frameworks can provide important indications for decision-making on allocation and distribution of resources for intervention efforts [78-83]. Case studies using qualitative research can provide insight into informal reasons for successful implementers and non-adopters that are not identified in survey studies. This will validate generalizability. Cross-national studies can provide information on global commonalities or regional differences, helping to inform education technology at the global and regional scales [84-87]. The development and verification of reduced assessment tools, using items identified in this research as most predictive, could enable monitoring that informs implementation progress. An assessment of student outcomes across various levels and types of GeoGebra would provide the ultimate verification of efforts to implement change. An assessment of sustainability during implementation, particularly in the post-support phase, would inform long-term strategies [88-91].

6- Conclusion

This extensive research has shown that GeoGebra has never been fully implemented in Greek secondary mathematics education, as attitudes and perceived merit did not translate into classroom practice for various reasons operating at different levels. The general implementation score ($M = 2.21$) is far below the threshold for moderation and does not reflect personal failure; rather, it reflects a misfit between support and innovation.

Leverage points for intervention are clearly identified by the empirical data: the threshold-level B2 professional development and the critical window of experience between 6-10 years of teaching. Mathematical content variation—including Geometry's success and Statistics' limited implementation—requires that interventions account for distinct difficulties in technology implementation.

The Contextual Implementation Cascade Framework, derived from this work, offers a framework for understanding and addressing the various factors that shape educational technology adoption. This framework goes beyond traditional technology acceptance frameworks to include the various influences on successful or unsuccessful implementation in educational settings.

The implications are not limited to GeoGebra or Greek education but contribute to generalizations about integration efforts within educational technology in resource-constrained environments. The paradox between perceived and actual usage could well be applicable to most other educational innovations. For success to be achieved, fragmented efforts must give way to integrated strategies addressing the issue on various fronts: infrastructural development, personnel development, culture change, and orientation.

7- Declarations

7-1- Author Contributions

Conceptualization, G.V., H.A., Z.K., and C.H.; methodology, G.V., H.A., Z.K., and C.H.; software, G.V. and H.A.; validation, Z.K. and C.H.; formal analysis, C.H.; investigation, G.V., H.A., and Z.K.; resources, Z.K. and C.H.; data curation, G.V., H.A., Z.K., and C.H.; writing—original draft preparation, G.V., H.A., Z.K., and C.H.; writing—review and editing, G.V., H.A., Z.K., and C.H.; visualization, G.V., H.A., Z.K., and C.H.; funding acquisition, G.V., H.A., Z.K., and C.H. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7-3- Funding

The publication fees of this manuscript have been financed by the Research Council of the University of Patras, Greece.

7-4- Institutional Review Board Statement

Ethical review and approval were waived for this study, due to the University of Patras Ethics Committee and Research Ethics guidelines, as ethical approval is not required for studies involving anonymous survey-based research, mainly when the participants are healthy adults, not from vulnerable populations, and the study does not collect sensitive or identifiable personal data.

7-5- Informed Consent Statement

Informed consent was obtained from all subjects involved in this study.

7-6- Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

8- References

[1] Yohannes, A., & Chen, H. L. (2023). GeoGebra in mathematics education: a systematic review of journal articles published from 2010 to 2020. Interactive Learning Environments, 31(9), 5682–5697. doi:10.1080/10494820.2021.2016861.

[2] Gökçe, S., & Güner, P. (2022). Dynamics of GeoGebra ecosystem in mathematics education. Education and Information Technologies, 27(4), 5301–5323. doi:10.1007/s10639-021-10836-1.

[3] Engelbrecht, J., & Borba, M. C. (2024). Recent developments in using digital technology in mathematics education. ZDM - Mathematics Education, 56(2), 281–292. doi:10.1007/s11858-023-01530-2.

[4] Awaji, B. M., Khalil, I., & AL-Zahrani, A. (2025). A Bibliometrics Study of Two Decades of Geogebra Research in Mathematics Education. Journal of Educational and Social Research, 15(1), 130–150. doi:10.36941/jesr-2025-0011.

[5] Sayaf, A. M., Alamri, M. M., Alqahtani, M. A., & Al-Rahmi, W. M. (2021). Information and communications technology used in higher education: An empirical study on digital learning as sustainability. Sustainability (Switzerland), 13(13), 7074. doi:10.3390/su13137074.

[6] Tavares, M. C., Azevedo, G., & Marques, R. P. (2022). The Challenges and Opportunities of Era 5.0 for a More Humanistic and Sustainable Society—A Literature Review. Societies, 12(6), 149. doi:10.3390/soc12060149.

[7] Pan, Y., Ke, F., & Xu, X. (2022). A systematic review of the role of learning games in fostering mathematics education in K-12 settings. Educational Research Review, 36, 100448. doi:10.1016/j.edurev.2022.100448.

[8] Tzachrista, M., Gkintoni, E., & Halkiopoulos, C. (2023). Neurocognitive Profile of Creativity in Improving Academic Performance—A Scoping Review. Education Sciences, 13(11), 1127. doi:10.3390/educsci13111127.

[9] Bobryshov, S. V., Sumenko, L. V., Toiskin, V. S., Taran, O. A., & Babayan, A. V. (2022). Paradigmatic Shifts in Education: Causes, Effects, and Risks. Education in the Asia-Pacific Region, 65, 397–405. doi:10.1007/978-981-16-9069-3_44.

[10] Biplob, K. B. B., Hashim, M. A., Hossain, M. E., Bitto, A. K., Hassan, S. N. S., & Sultana, M. (2025). The Impact of Higher Secondary ICT Education on University STEM Student Performance. Emerging Science Journal, 9, 230–242. doi:10.28991/ESJ-2025-SIED1-014.

[11] Alam, A. (2022). Cloud-Based E-Learning: Development of Conceptual Model for Adaptive E-Learning Ecosystem Based on Cloud Computing Infrastructure. Communications in Computer and Information Science, 1673 CCIS, 377–391. doi:10.1007/978-3-031-21385-4_31.

[12] Aldon, G., Cusi, A., Schacht, F., & Swidan, O. (2021). Teaching mathematics in a context of lockdown: A study focused on teachers' praxeologies. Education Sciences, 11(2), 1–21. doi:10.3390/educsci11020038.

[13] Toma, F., Ardelean, A., Grădinaru, C., Nedelea, A., & Diaconu, D. C. (2023). Effects of ICT Integration in Teaching Using Learning Activities. Sustainability (Switzerland), 15(8), 6885. doi:10.3390/su15086885.

[14] Abedi, E. A. (2024). Tensions between technology integration practices of teachers and ICT in education policy expectations: implications for change in teacher knowledge, beliefs and teaching practices. Journal of Computers in Education, 11(4), 1215–1234. doi:10.1007/s40692-023-00296-6.

[15] Valverde-Berrocoso, J., Fernández-Sánchez, M. R., Dominguez, F. I. R., & Sosa-Díaz, M. J. (2021). The educational integration of digital technologies preCovid-19: Lessons for teacher education. PLoS ONE, 16(8 August), 256283. doi:10.1371/journal.pone.0256283.

[16] Nzaramyimana, E. (2021). Effectiveness of GeoGebra towards Students' Active Learning, Performance and Interest to Learn Mathematics. International Journal of Mathematics and Computer Research, 9(10), 2423–2430. doi:10.47191/ijmcr/v9i10.05.

[17] Haldorai, A., Murugan, S., & Ramu, A. (2021). Evolution, challenges, and application of intelligent ICT education: An overview. Computer Applications in Engineering Education, 29(3), 562–571. doi:10.1002/cae.22217.

[18] Chee, H., Ahn, S., & Lee, J. (2025). A Competency Framework for AI Literacy: Variations by Different Learner Groups and an Implied Learning Pathway. British Journal of Educational Technology, 56(5), 2146–2182. doi:10.1111/bjet.13556.

[19] Tondeur, J., Howard, S., Van Zanten, M., Gorissen, P., Van der Neut, I., Uerz, D., & Kral, M. (2023). The HeDiCom framework: Higher Education teachers' digital competencies for the future. Educational Technology Research and Development, 71(1), 33–53. doi:10.1007/s11423-023-10193-5.

[20] von Kotzebue, L., Meier, M., Finger, A., Kremser, E., Huwer, J., Thoms, L. J., Becker, S., Bruckermann, T., & Thyssen, C. (2021). The framework dikolan (Digital competencies for teaching in science education) as basis for the self-assessment tool dikolan-grid. Education Sciences, 11(12), 775. doi:10.3390/educsci11120775.

[21] Wu, D., Xu, H., Sun, Y., & Lv, S. (2023). What should we teach? A human-centered data science graduate curriculum model design for iField schools. Journal of the Association for Information Science and Technology, 74(6), 623–640. doi:10.1002/asi.24644.

[22] Jackson, I., Gonzales, M. M., & Mensah, A. (2022). It is not equitable if it is not culturally sustaining: teaching and learning in 1:1 laptop schools. Journal for Multicultural Education, 16(4), 323–336. doi:10.1108/JME-09-2021-0180.

[23] Atay, S., Terzi Müftüoğlu, C., Gülmez, N., & Şahin, M. (2025). Society 5.0 and human-centered technology: Redefining talent management in the digital age. Sustainable Futures, 9, 100733. doi:10.1016/j.sftr.2025.100733.

[24] Koul, S., & Nayar, B. (2021). The holistic learning educational ecosystem: A classroom 4.0 perspective. Higher Education Quarterly, 75(1), 98–112. doi:10.1111/hequ.12271.

[25] Al-Adwan, A. S., Albelbisi, N. A., Hujran, O., Al-Rahmi, W. M., & Alkhalifah, A. (2021). Developing a holistic success model for sustainable e-learning: A structural equation modeling approach. Sustainability (Switzerland), 13(16), 9453. doi:10.3390/su13169453.

[26] Halkiopoulos, C., & Gkintoni, E. (2024). Leveraging AI in E-Learning: Personalized Learning and Adaptive Assessment through Cognitive Neuropsychology—A Systematic Analysis. Electronics (Switzerland), 13(18), 3762. doi:10.3390/electronics13183762.

[27] Castañeda, L., Esteve-Mon, F. M., Adell, J., & Prestridge, S. (2022). International insights about a holistic model of teaching competence for a digital era: the digital teacher framework reviewed. European Journal of Teacher Education, 45(4), 493–512. doi:10.1080/02619768.2021.1991304.

[28] Yorganci, S., & Subasi, M. (2025). Interactive GeoGebra applets to improving students' learning performance in e-book-based learning environment. Education and Information Technologies, 30(5), 5477–5500. doi:10.1007/s10639-024-13021-2.

[29] Christensen, J. H. (2022). Enhancing mixed methods pragmatism with systems theory: Perspectives from educational research. Systems Research and Behavioral Science, 39(1), 104–115. doi:10.1002/sres.2751.

[30] Hamari, J., Koivisto, J., & Sarsa, H. (2014). Does gamification work? - A literature review of empirical studies on gamification. Proceedings of the Annual Hawaii International Conference on System Sciences, 3025–3034. doi:10.1109/HICSS.2014.377.

[31] Dicheva, D., Dichev, C., Agre, G., & Angelova, G. (2015). Gamification in education: A systematic mapping study. Educational Technology and Society, 18(3), 75–88.

[32] Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. International Journal of Human Computer Studies, 74, 14–31. doi:10.1016/j.ijhcs.2014.09.006.

[33] Kapp, K. M. (2012). The gamification of learning and instruction: Game-based methods and strategies for training and education. John Wiley & Sons, Hoboken, United States.

[34] Sailer, M., Hense, J. U., Mayr, S. K., & Mandl, H. (2017). How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. Computers in Human Behavior, 69, 371–380. doi:10.1016/j.chb.2016.12.033.

[35] Attali, Y., & Arieli-Attali, M. (2015). Gamification in assessment: Do points affect test performance? Computers and Education, 83, 57–63. doi:10.1016/j.compedu.2014.12.012.

[36] Caponetto, I., Earp, J., & Ott, M. (2014). Gamification and education: A literature review. Proceedings of the European Conference on Games-Based Learning, 1, 50–57.

[37] Bruner, J. S. (2020). The Act of Discovery. Search of Pedagogy Volume I, 31(1), 67–76. doi:10.4324/9780203088609-13.

[38] Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. (2011). Does Discovery-Based Instruction Enhance Learning? Journal of Educational Psychology, 103(1), 1–18. doi:10.1037/a0021017.

[39] De Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. Review of Educational Research, 68(2), 179–201. doi:10.3102/00346543068002179.

[40] Mayer, R. E. (2004). Should There Be a Three-Strikes Rule against Pure Discovery Learning? The Case for Guided Methods of Instruction. American Psychologist, 59(1), 14–19. doi:10.1037/0003-066X.59.1.14.

[41] Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational Psychologist, 41(2), 75–86. doi:10.1207/s15326985ep4102_1.

[42] Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: Defining "gamification." Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments, MindTrek 2011, 9–15. doi:10.1145/2181037.2181040.

[43] Hohenwarter, M., & Preiner, J. (2007). Dynamic mathematics with GeoGebra. Journal of online Mathematics and its applications, 7(1), 2-12.

[44] Hohenwarter, M. (2002). GeoGebra - a software system for dynamic geometry and algebra in the plane. Master's thesis, University of Salzburg, Salzburg, Austria.

[45] Hohenwarter, M., & Fuchs, K. (2004). Combination of dynamic geometry, algebra and calculus in the software system GeoGebra. Proceedings of the Computer Algebra Systems and Dynamic Geometry Systems in Mathematics Teaching Conference, Pécs, Hungary.

[46] Lavicza, Z. (2010). Integrating technology into mathematics teaching at the university level. ZDM - International Journal on Mathematics Education, 42(1), 105–119. doi:10.1007/s11858-009-0225-1.

[47] Preiner, J. (2008). Introducing dynamic mathematics software to mathematics teachers: The case of GeoGebra. Doctoral Dissertation, University of Salzburg, Salzburg, Austria.

[48] Botana, F., Hohenwarter, M., Janičić, P., Kovács, Z., Petrović, I., Recio, T., & Weitzhofer, S. (2015). Automated Theorem Proving in GeoGebra: Current Achievements. Journal of Automated Reasoning, 55(1), 39-59. doi:10.1007/s10817-015-9326-4.

[49] Kovács, Z., Recio, T., & Vélez, M. P. (2018). Using automated reasoning tools in GeoGebra in the teaching and learning of proving in geometry. International Journal for Technology in Mathematics Education, 25(2), 33–51. doi:10.1564/tme_v25.2.03.

[50] King, W. R., & He, J. (2006). A meta-analysis of the technology acceptance model. Information and Management, 43(6), 740–755. doi:10.1016/j.im.2006.05.003.

[51] Zambeta, E. (2014). Education in times of crisis. Education Inquiry, 5(1), 24042. doi:10.3402/edui.v5.24042.

[52] Birch, C. (2011). Rethinking Education in the Age of Technology: The Digital Revolution and Schooling in America by Allan Collins and Richard Halverson. American Journal of Education, 117(3), 659215. doi:10.1086/659215.

[53] Means, B. (2010). Technology and education change: Focus on student learning. Journal of Research on Technology in Education, 42(3), 285–307. doi:10.1080/15391523.2010.10782552.

[54] Dede, C. (2008). Theoretical Perspectives Influencing the Use of Information Technology in Teaching and Learning. In J. Voogt & G. Knezek (Eds.), International Handbook of Information Technology in Primary and Secondary Education. Springer, 43–62. doi:10.1007/978-0-387-73315-9_3.

[55] Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. Journal of Research on Technology in Education, 42(3), 255–284. doi:10.1080/15391523.2010.10782551.

[56] Fullan, M. (2013). Stratosphere: Integrating technology, pedagogy, and change knowledge. Alberta Journal of Educational Research, 62(4), 429-432.

[57] Puentedura, R. R. (2006). Transformation, technology, and education. Hippasus, United States. Available online: http://hippasus.com/resources/tte/ (accessed on February 2026).

[58] Ebina Justin, M. A., & Joy, M. M. (2023). Exploring Intrinsic Motivating Factors in Gamified Context: A Mixed-Method Study. International Journal of Human-Computer Interaction, 39(19), 3728–3744. doi:10.1080/10447318.2022.2104018.

[59] Christopoulos, A., & Mystakidis, S. (2023). Gamification in Education. Encyclopedia, 3(4), 1223–1243. doi:10.3390/encyclopedia3040089.

[60] Clanton Harpine, E. (2024). Creating an Intrinsically Motivating Learning Environment: Promoting Student Engagement and Intrinsic Motivation. Service Learning in Higher Education. Springer Nature, 59–76. doi:10.1007/978-3-031-51378-7_5.

[61] Jones, M., Blanton, J. E., & Williams, R. E. (2023). Science to practice: Does gamification enhance intrinsic motivation? Active Learning in Higher Education, 24(3), 273–289. doi:10.1177/14697874211066882.

[62] Saif, S. M., Ansarullah, S. I., Othman, M. T. Ben, Alshmrany, S., Shafiq, M., & Hamam, H. (2022). Impact of ICT in Modernizing the Global Education Industry to Yield Better Academic Outreach. Sustainability (Switzerland), 14(11), 6884. doi:10.3390/su14116884.

[63] Rahimi, R. A., & Oh, G. S. (2024). Rethinking the role of educators in the 21st century: navigating globalization, technology, and pandemics. Journal of Marketing Analytics, 12(2), 182–197. doi:10.1057/s41270-024-00303-4.

[64] Kanvaria, V. K., & Yadav, A. (2024). Integrating and Innovating: The Role of ICT in Education's Evolution-An In-depth Analysis of Emerging Technologies, Current Trends, Challenges, and Future Directions in the Digital Age. International Journal for Multidimensional Research Perspectives, 2(2), 33–48.

[65] Oller, J., Engel, A., & Rochera, M. J. (2021). Personalizing learning through connecting students' learning experiences: an exploratory study. Journal of Educational Research, 114(4), 404–417. doi:10.1080/00220671.2021.1960255.

[66] Antonova, A., & Dankov, Y. (2023). Smart Services in Education: Facilitating Teachers to Deliver Personalized Learning Experiences. Lecture Notes in Networks and Systems, 597 LNNS, 108–117. doi:10.1007/978-3-031-21438-7_9.

[67] Lawrence, L. E. M., Echeverria, V., Yang, K., Aleven, V., & Rummel, N. (2024). How teachers conceptualise shared control with an AI co-orchestration tool: A multiyear teacher-centred design process. British Journal of Educational Technology, 55(3), 823–844. doi:10.1111/bjet.13372.

[68] Amarasinghe, I., Michos, K., Crespi, F., & Hernández-Leo, D. (2024). Learning analytics support to teachers' design and orchestrating tasks. Journal of Computer Assisted Learning, 40(6), 2416–2431. doi:10.1111/jcal.12711.

[69] Ortega-Arranz, A., Amarasinghe, I., Martínez-Monés, A., Asensio-Pérez, J. I., Dimitriadis, Y., Corrales-Astorgano, M., & Hernández-Leo, D. (2024). Collaborative activities in hybrid learning environments: Exploring teacher orchestration load and students' perceptions. Computers and Education, 219, 105105. doi:10.1016/j.compedu.2024.105105.

[70] Zhao, Z., & Feng, G. (2022). Orchestration of learning environments in the digital world. Interactive Learning Environments, 1–5. doi:10.1080/10494820.2022.2144896.

[71] Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. MIS Quarterly: Management Information Systems, 27(3), 425–478. doi:10.2307/30036540.

[72] Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. Teachers College Record, 108(6), 1017–1054. doi:10.1111/j.1467-9620.2006.00684.x.

[73] Hall, G. E., & Hord, S. M. (2011). Implementing change: Patterns, principles, and potholes (3rd ed.). Pearson, Boston, United States.

[74] Copur-Gencturk, Y., & Li, J. (2023). Teaching matters: A longitudinal study of mathematics teachers' knowledge growth. Teaching and Teacher Education, 121, 103949. doi:10.1016/j.tate.2022.103949.

[75] Alexaki, P. S., Antonopoulou, H., Gkintoni, E., Adamopoulos, N., & Halkiopoulos, C. (2025). Psychological Dimensions of Professional Burnout in Special Education: A Cross-Sectional Behavioral Data Analysis of Emotional Exhaustion, Personal Achievement, and Depersonalization. International Journal of Environmental Research and Public Health, 22(9). doi:10.3390/ijerph22091420.

[76] Maready, B., Cheng, Q., & Bunch, D. (2021). Exploring Mentoring Practices Contributing to New Teacher Retention: An Analysis of the Beginning Teacher Longitudinal Study. International Journal of Evidence Based Coaching and Mentoring, 19(2), 88–99. doi:10.24384/rgm9-sa56.

[77] Savolainen, H., Malinen, O. P., & Schwab, S. (2022). Teacher efficacy predicts teachers' attitudes towards inclusion–a longitudinal cross-lagged analysis. International Journal of Inclusive Education, 26(9), 958–972. doi:10.1080/13603116.2020.1752826.

[78] Ruiz-Rojas, L. I., Salvador-Ullauri, L., & Acosta-Vargas, P. (2024). Collaborative Working and Critical Thinking: Adoption of Generative Artificial Intelligence Tools in Higher Education. Sustainability (Switzerland) , 16(13), 5367. doi:10.3390/su16135367.

[79] Strat, T. T. S., Henriksen, E. K., & Jegstad, K. M. (2024). Inquiry-based science education in science teacher education: a systematic review. Studies in Science Education, 60(2), 191–249. doi:10.1080/03057267.2023.2207148.

[80] Van Katwijk, L., Jansen, E., & Van Veen, K. (2023). Pre-service teacher research: a way to future-proof teachers? European Journal of Teacher Education, 46(3), 435–455. doi:10.1080/02619768.2021.1928070.

[81] Sortwell, A., Trimble, K., Ferraz, R., Geelan, D. R., Hine, G., Ramirez-Campillo, R., Carter-Thuiller, B., Gkintoni, E., & Xuan, Q. (2024). A Systematic Review of Meta-Analyses on the Impact of Formative Assessment on K-12 Students' Learning: Toward Sustainable Quality Education. Sustainability (Switzerland), 16(17), 7826. doi:10.3390/su16177826.

[82] Chan, M. ki, Sharkey, J. D., Lawrie, S. I., Arch, D. A. N., & Nylund-Gibson, K. (2021). Elementary School Teacher Well-Being and Supportive Measures Amid COVID-19: An Exploratory Study. School Psychology, 36(6), 533–545. doi:10.1037/spq0000441.

[83] Walter, H. L., & Fox, H. B. (2021). Understanding Teacher Well-Being During the Covid-19 Pandemic Over Time: A Qualitative Longitudinal Study. Journal of Organizational Psychology, 21(5), 23–40. doi:10.33423/jop.v21i5.4716.

[84] Sortwell, A., Gkintoni, E., Díaz-García, J., Ellerton, P., Ferraz, R., & Hine, G. (2026). Beyond Cognitive Load Theory: Why Learning Needs More than Memory Management. Brain Sciences, 16(1), 109. doi:10.3390/brainsci16010109.

[85] Cai, J., Mok, I. A. C., Reddy, V., & Stacey, K. (2017). International Comparative Studies in Mathematics: Lessons and Future Directions for Improving Students' Learning. Proceedings of the 13th International Congress on Mathematical Education, Springer, 79–99. doi:10.1007/978-3-319-62597-3_6.

[86] Sortwell, A., Evgenia, G., Zagarella, S., Granacher, U., Forte, P., Ferraz, R., Ramirez-Campillo, R., Carter-Thuillier, B., Konukman, F., Nouri, A., Bentley, B., Marandi, P., & Jemni, M. (2023). Making neuroscience a priority in Initial Teacher Education curricula: a call for bridging the gap between research and future practices in the classroom. Neuroscience Research Notes, 6(4). doi:10.31117/neuroscirn.v6i4.266.

[87] Yang, X., Chan, M. C. E., Kaur, B., Deng, J., Luo, J., & Wen, Y. (2025). International comparative studies in mathematics education: a scoping review of the literature from 2014 to 2023. ZDM - Mathematics Education, 57(4), 745–761. doi:10.1007/s11858-025-01700-4.

[88] Bekene Bedada, T., & Machaba, M. F. (2022). The Effect of GeoGebra on Students' Abilities to Study Calculus. Education Research International, 2022, 4400024. doi:10.1155/2022/4400024.

[89] Uwurukundo, M. S., Maniraho, J. F., Tusiime, M., Ndayambaje, I., & Mutarutinya, V. (2024). GeoGebra software in teaching and learning geometry of 3-dimension to improve students' performance and attitude of secondary school teachers and students. Education and Information Technologies, 29(8), 10201–10223. doi:10.1007/s10639-023-12200-x.

[90] Birgin, O., & Topuz, F. (2021). Effect of the GeoGebra software-supported collaborative learning environment on seventh grade students' geometry achievement, retention and attitudes. Journal of Educational Research, 114(5), 474–494. doi:10.1080/00220671.2021.1983505.

[91] Birgin, O., & Uzun Yazıcı, K. (2021). The effect of GeoGebra software–supported mathematics instruction on eighth-grade students' conceptual understanding and retention. Journal of Computer Assisted Learning, 37(4), 925–939. doi:10.1111/jcal.12532.