Development of Algorithmic Competence of Students in Studying Mathematics: An Experimental Study of the Effectiveness of the Use of Information and Communication Technologies

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ABSTRACT: In today's world, education is faced with the challenge of incorporating information and communication technologies (ICT) to enhance the learning experience, particularly in mathematics. This research aims to determine the effect of ICT on the growth of algorithmic competency among students in Kazakhstan. Cultivating this skill set is crucial as it encompasses the capacity to tackle intricate mathematical problems by comprehending and utilizing algorithms, which is essential in a rapidly advancing digital society. The research relies on data analysis from global educational assessment initiatives like PISA (Program for International Student Assessment) and TIMSS (Trends in Mathematics and Science Study). These programs offer comprehensive insights into the present state of mathematical abilities among students in Kazakhstan. The findings highlight the need for substantial enhancements in mathematics education, especially in fostering algorithmic thinking skills. Integrating ICT into the learning process appears to be a powerful tool for attaining these objectives.

Keywords: ICT, algorithmic competence, mathematics teaching, dynamic geometry, GeoGebra, Desmos, computer-supported collaborative learning (CSCL), digitalization, education

I. INTRODUCTION

In today's world, information and communication technologies (ICT) play a crucial role in education, especially in the realm of mathematics. Research studies like the Program for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) highlight the significance of enhancing students' algorithmic skills. The results of PISA and TIMSS in Kazakhstan underscore the necessity of boosting mathematical abilities and algorithmic literacy among youth.

Algorithmic competence entails grasping and applying algorithms to tackle math problems, which is a foundational element of contemporary education [1]. Integrating ICT into math instruction can greatly enhance teaching efficiency and learning outcomes by equipping students with the resources to better comprehend and practice algorithms.

II. PROBLEM STATEMENT

In the Concept for the advancement of preschool, secondary, technical, and vocational education of the Republic of Kazakhstan for 2023 - 2029, it is noted in Paragraph 1, "Enhancing the content of secondary education", that educational institutions will have autonomy in selecting innovations by embracing the finest domestic and international practices, and creating and implementing diverse programs [2].

The introduction of innovative ways of teaching subjects is implemented through electronic platforms for teachers and students, which will lead to the digitalization of the entire educational process.

Content-rich platforms, high-quality textbooks and teaching-methodological complexes, and the use of tablets in the educational process will allow students to consistently and systematically develop skills in developing functional literacy in students, ensure visibility, accessibility, individuality of materials, and independence of schoolchildren.

All classes will have 100% coverage of invariant subjects with digital textbooks that have multimedia (audio, video), interactive content and functions with gamification elements. As a result, the competitiveness of students will increase, the educational process will improve, the burden on children and teachers will decrease, and the quality of education in general will improve [3].

1. DIFFICULTIES IN TEACHING ALGEBRA AND GEOMETRY IN THE SEVENTH GRADE.

In elementary algebra and geometry, especially in 7th grade, students often face a number of challenges that can hinder their understanding and success in learning. Research by foreign scientists reveals several key problems faced by adolescents at this age. First, many students have difficulty with the abstract thinking necessary to understand algebraic concepts. The abstract nature of the symbols and variables in algebra can be confusing to students, making it difficult for them to solve equations and problems. Secondly, in geometry, students often encounter problems with visualization and spatial imagination. This may manifest itself as difficulty understanding the properties of shapes, drawing graphs, and visualizing three-dimensional objects on a two-dimensional plane. Third, the problem of translating real-world situations into mathematical models (e.g., using equations to solve problems) is also common [4]. Students may not understand how to apply mathematical tools to real-world problems, hindering their ability to solve problems that require the use of algebra and geometry. Research also suggests that insufficient basic mathematics training may exacerbate these problems [5]. Students who have not mastered basic math concepts in previous grades may have additional difficulty learning more advanced topics in 7th grade. Thus, to improve the teaching of algebra and geometry in primary grades, it is necessary to pay attention not only to the complexity of the material, but also to the development of abstract thinking, visualization, and skills in translating real situations into mathematical models.

The results of a number of scientific studies conducted among schoolchildren of various age the groups suggest that utilizing the GeoGebra program in the educational process has a considerable beneficial effect on the efficiency of learning and academic achievements of students compared to traditional teaching methods without the use of specialized software.

2. DATA COLLECTION

Collaborative learning activities supported by computer tools and the introduction of multi-platform GeoGebra software into the educational process.

Education that focuses on the teacher and his knowledge rather than on the student is called traditional education. It mainly involves discussions led by the teacher and knowledge imparted by the teacher to the students. This approach has been criticized for encouraging rote learning and not ensuring knowledge durability [6].

In contrast, constructivism is an approach in which students actively construct their knowledge by building on their existing knowledge and new information [7]. The main advantage of constructivism is that it transforms the student from a passive listener into an engaged contributor to the educational process. Learners, with the support of an instructor, actively build their own understanding instead of merely absorbing information from the educator or textbooks [8]. In a constructivist learning setting, the educator facilitates students as they navigate problem-solving and exploration, encouraging collaboration among them to investigate and refine their concepts and reach conclusions and share knowledge [9].

According to Takachi et al. (2015), GeoGebra is a computer application that promotes social interaction by creating a dynamic learning environment. GeoGebra provides a platform for small group discussions of mathematical ideas, collaborative problem solving, and deductive reasoning. It helps structure mathematical concepts, explain geometric relationships, and facilitates the proof process [10].

Ozkan and Oner conducted an conducted an experiment with high school students and discovered that employing GeoGebra in a CSCL environment significantly improved students' geometric thinking level even with short-term training [11]. Abdu et al. (2015) note that whole-class support in a CSCL environment helps students solve math problems collaboratively [12].

Overall, prior research suggests that, due to its dynamic properties, GeoGebra can provide multiple opportunities for students to acquire knowledge geometry concepts in a collaborative computer-based learning environment.

3. HYPOTHESIS TESTING.

This study used a quasi-experimental method with control and experimental groups, including preliminary and final testing, as well as a test for the strength of knowledge acquisition.

The research design is depicted in Figure 1. Quasi-experimental methods are often preferred in situations where random assignment of participants to experimental and control groups is not possible [13].

In this regard, seventh grade students from a government high school were selected to form experimental and control groups. Maintaining a natural classroom environment was ensured, as random assignment of participants was not possible due to the organizational structure of the Kazakh school system. Two selected groups were randomly assigned as control and experimental.

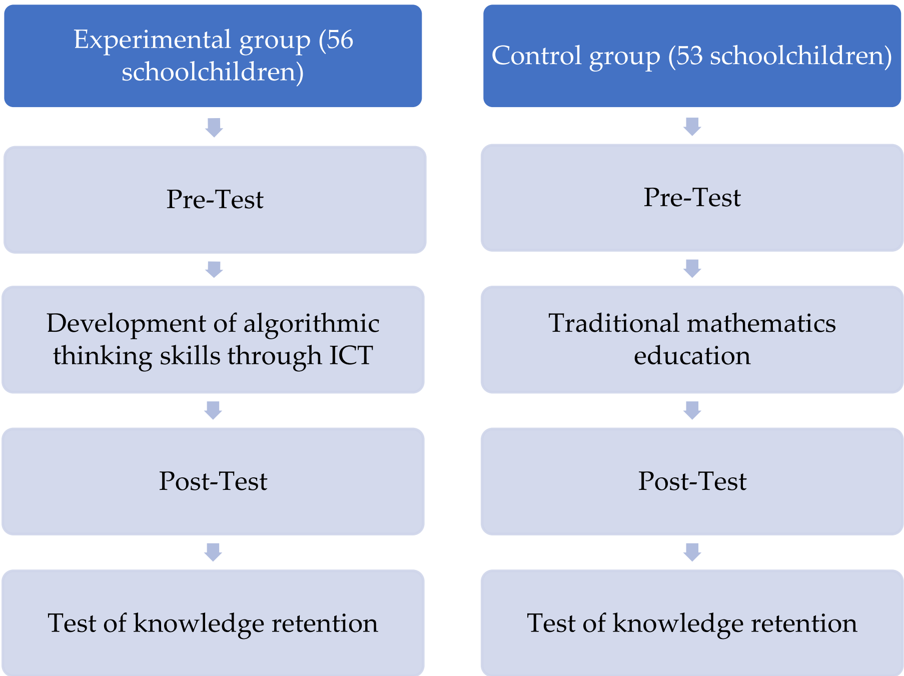

FIGURE 1. Study design

4. EXPERIMENT PARTICIPANTS

Participants in the quasi-experiment included 109 seventh-grade students (12 to 13 years old) at a public secondary school located in the central area of a city in the northern part of Kazakhstan. The control group was made up of 53 students (26 girls and 27 boys), while the experimental group comprised 56 students (27 girls and 29 boys).

This circumstance provides researchers with direct access to the educational process, allows them to better understand the specifics of teaching mathematics in a given school and establish trusting relationships with students and colleagues. In addition, the author's personal involvement in the life of the school contributes to a more effective organization of research and obtaining reliable data.

5. INSTRUMENTS FOR GATHERING DATA

Two tools were employed for data collection in the research: the Mathematics Aptitude Test (MAT), developed by the researchers, and the Mathematics Attitude Scale (MAS), developed in 2004 and used PISA and TIMSS, The MAT was a test consisting of 20 multiple choice questions covering subjects included in the seventh-grade math syllabus [23]. Given that initial testing (pre-test) was scheduled and conducted at the start of the academic year, it necessitated a meticulous choice of tasks matching the students' knowledge and skill level at that point. With this consideration, the test comprised tasks that encompassed content taught within the school's curriculum for grades 5 and 6. This approach allowed us to adequately assess students' basic knowledge and create a basis for further monitoring of their progress during the school year [22].

To process statistical data through the partial least squares (PLS) method, we used the following notation:
- INT - Interest in mathematics
- CONF - Confidence in Mathematics
- USE - Usefulness of Mathematics
- SAT - Satisfaction with Problem Solving
- COMP - Comparison of mathematics with other subjects
- LIKE - I like solving math problems
- IMP - The Importance of Understanding Mathematics
- FUT - Mathematics Help for the Future
- COMF - Comfort while learning new concepts
- CAREER - Math help in your career

These notations make it possible to more compactly and clearly present various aspects of attitudes towards mathematics, which simplifies the analysis and interpretation of the results obtained using the PLS method. Because our goal is to determine which factors influence interest in mathematics and how they are related, we used correlation or factor analysis to determine the strength of the relationship between interest in mathematics (INT) and the remaining variables [24].

1. Confidence in mathematics (CONF): High confidence in mathematics skills could positively influence interest in mathematics. Therefore, a positive correlation between the INT and CONF variables could be expected.
2. Usefulness of Mathematics (USE): If students saw practical value in learning mathematics, this could also positively influence their interest in the subject. A positive correlation could be expected between the INT and USE variables.
3. Satisfaction in Solving Problems (SAT): If students felt satisfaction from solving math problems, it could increase their interest in mathematics. Therefore, a positive correlation between the INT and SAT variables could be expected [25].
4. Comparing Mathematics with Other Subjects (COMP): Students could compare their interest in mathematics with their interest in other subjects. The positive comparison may have strengthened their interest in mathematics. A positive correlation could be expected between the INT and COMP variables.
5. Like solving math problems (LIKE): It was assumed that people who enjoyed solving math problems tended to be more interested in math itself. Therefore, a positive correlation could be expected between the INT and LIKE variables.
6. Importance of Understanding Mathematics (IMP): If students perceived understanding mathematics as important to their education, they might be more interested in it. Therefore, a positive correlation between the INT and IMP variables could be expected.
7. Helping Mathematics in the Future (FUT): If students saw the potential benefits of mathematics in their future life, they might be more interested in it. A positive correlation could be expected between the INT and FUT variables.
8. Comfort in learning new concepts (COMF): Comfort and ease in learning new mathematical concepts may have contributed to increased interest in mathematics. A positive correlation could be expected between the INT and COMF variables.
9. Mathematics Help in Careers (CAREER): If students believed that mathematics would help them in their future careers, it could increase their interest in the subject. Therefore, a positive correlation could be expected between the INT and CAREER variables [26].

To test our hypotheses about the relationship between interest in mathematics (INT) and various factors such as confidence in mathematics (CONF), usefulness of mathematics (USE), satisfaction with problem solving (SAT), comparison of mathematics with other subjects (COMP), enjoyment from solving math problems (LIKE), importance of understanding math (IMP), future math help (FUT), comfort in learning new concepts (COMF), and math help in career (CAREER), we conducted a correlation analysis [27]. The outcomes of the evaluation are presented in a path diagram (Figure 1).

The path diagram clearly demonstrates the relationships between interest in mathematics and the factors considered. The arrows indicate the direction of influence, and the numbers next to the arrows are path coefficients or standardized regression coefficients, showing the strength and direction of the relationship between variables [28].

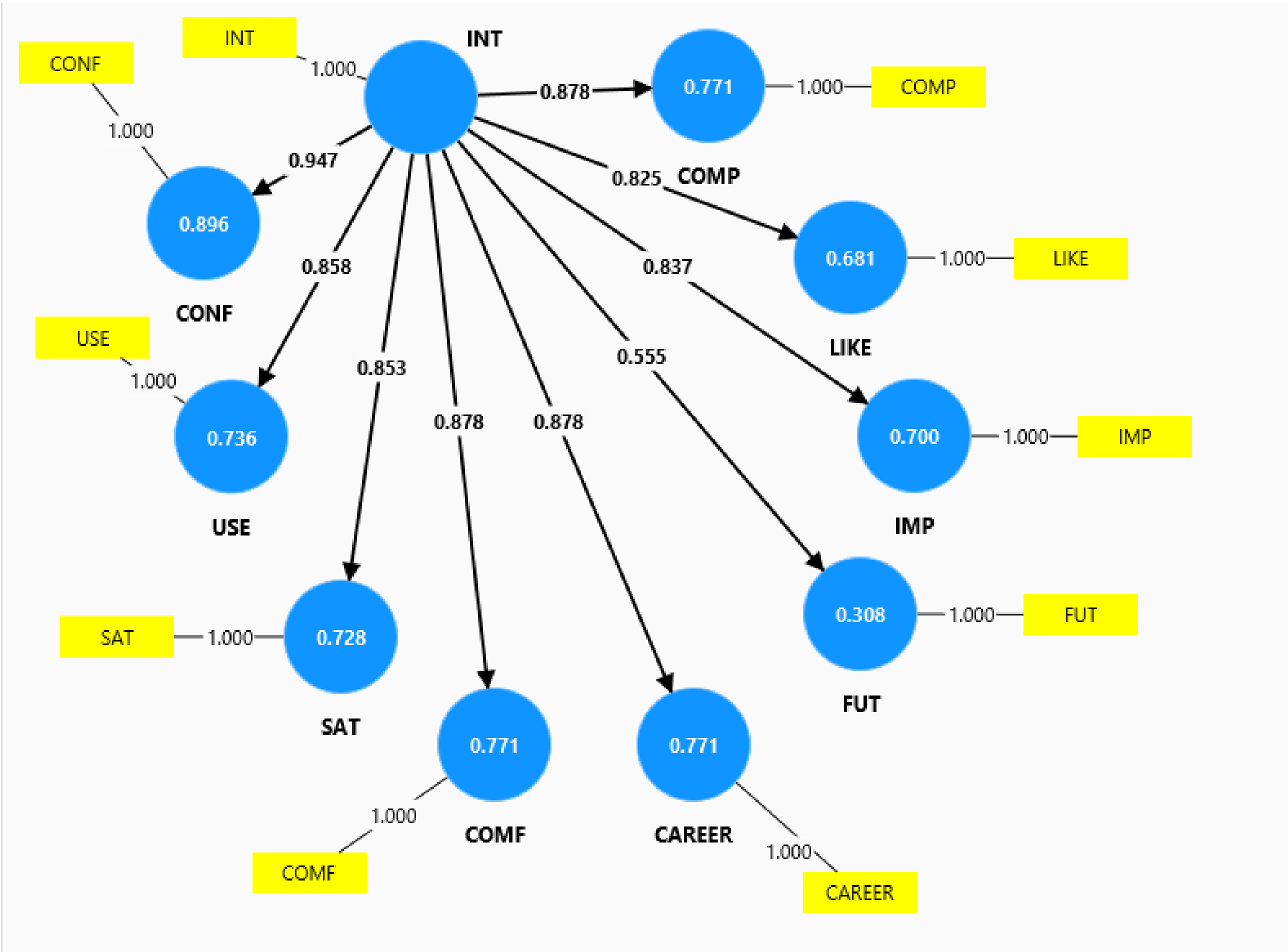

FIGURE 2.Structural Equation Modeling Diagram.

According to Table 1, the CONF parameter has the highest values of R-square and R-square adjusted (0.896 and 0.895, respectively). This suggests that this parameter is best described by the regression model. The parameters CAREER, COMF and COMP have the same R-square and R-square adjusted values (0.771 and 0.768), which also indicates a good fit of the model to the data.

Table 1. Determination coefficients

	R-square	R-square adjusted
CAREER	0.771	0.768
COMF	0.771	0.768
COMP	0.771	0.768
CONF	0.896	0.895
FUT	0.308	0.300
IMP	0.700	0.697
LIKE	0.681	0.677
SAT	0.728	0.725
USE	0.736	0.733

The parameters IMP, USE, SAT and LIKE have R-square values ranging from 0.681 to 0.736, and adjusted R-square values from 0.677 to 0.733. This indicates a fairly high explanatory power of the model for these parameters. The smallest values of R-square (0.308) and R-square adjusted (0.300) are for the FUT parameter. The regression model describes the variability of this parameter worst of all compared to the others.

Overall, with the exception of the FUT parameter, the regression model shows a good fit to the data, explaining from 68% to 90% of the variation in parameter values. This allows the model to be used to predict and analyze relationships between variables [29].

6. DEVELOPMENT OF EDUCATIONAL MATERIALS WITH SUPPORT FOR THE DYNAMIC ENVIRONMENT GEOGEBRA AND DESMOS

The authors developed educational and methodological manual "Optional course for teaching mathematics at school through digital resources Geogebra and Desmos." The educational manual presents theoretical material about development of algorithmic competence of students in the context of digitalization of education; considered modern digital resources GeoGebra and Desmos, work in these programs and their advantages. The manual contains educational and thematic planning of an elective course for 7th grade students of a comprehensive school. Problems and their solutions are proposed using the interactive geometric environment GeoGebra and the graphic calculator Desmos. The manual will be useful for teachers of secondary schools and students of pedagogical universities.

7. THE EDUCATIONAL APPROACH IN BOTH THE EXPERIMENTAL AND CONTROL GROUPS

In the experimental group, instruction was facilitated through the use of the dynamic GeoGebra platform and the Desmos graphing calculator. Meanwhile, the control group received education via conventional teaching methods, offering a consistent framework for knowledge acquisition. It's significant to mention that a single mathematics instructor taught both groups. During the period of the research, the mathematics teacher had approximately 16 years of professional experience, a university degree, and knowledge and experience using GeoGebra software. Group instruction began in the same week and lasted a total of 34 sessions of 40 minutes each and followed the mathematics curriculum plan.

As part of the study, two groups of students were identified: experimental and control. In the experimental group, the learning process was organized using modern technological tools, such as the GeoGebra dynamic environment and the Desmos graphic calculator. These software solutions help you visualize math concepts and make complex ideas easier to understand.

In the control group, education was delivered through conventional techniques, offering learners a recognizable and consistent method for learning. It's important to highlight that the same highly skilled mathematics teacher instructed both groups. At the time of the research, this educator had around 16 years of teaching experience and possessed an advanced degree in mathematics. In addition, the teacher had knowledge and practical skills in using GeoGebra software, which made it possible to effectively use this tool in the experimental group.

Training in both groups started simultaneously and continued for 34 sessions, each of which lasted 40 minutes. The training program fully complied with the approved curriculum plan in mathematics, which provided equal conditions for students in both groups and made it possible to impartially evaluate the effect of the employed techniques on the study's outcomes.

8. ANALYSIS OF DATA

In this study, two instruments were used to evaluate the results:

8.1 Mathematics Test (MAT):

- Correct answers to multiple choice questions were worth 1 point.
- Incorrect or missing answers were scored 0 points.

8.2 Mathematics Attitude Scale (MAS):

- Positive statements were rated on a scale from 1 (strongly disagree) to 5 (strongly agree).
- Negative statements were scored in reverse.

Higher scores on the MAS indicated more positive attitudes toward mathematics.

Data obtained from MAT and MAS were analyzed using SPSS 17.0 statistical software. An independent samples t-test was used to compare group scores before the MAT and MAS. An analysis of covariance (ANCOVA) was conducted with pretest as a covariate to determine the effect of training on the groups' scores on the posttest and delayed tests on the MAT, as well as on the posttest scores on the MAS.

Basic assumptions for the t test and ANCOVA were tested before conducting the analysis. The normality of the distribution of scores in groups was checked using histograms, boxplots, skewness and kurtosis coefficients, and the Shapiro-Wilk test. As can be seen in Table 2, skewness and kurtosis values ranged from -

1 to +1, and the results of the Shapiro-Wilk test were not significant (p > .05), indicating that the assumption of normality of the variables was met. Multivariate normality was tested using Mahalanobis distance values and the assumption of multivariate normal distribution was found to be met.

Homogeneity of pretest variances was tested using Levene's test for homogeneity of variance. The results of Levene's test showed (Table 2) that the conditions for variance uniformity in the pre-MAT [F(1–106) = 0.223, p > .05] and pre-MAS [F(1–106) = 2.587, p > .05] were not violated. In addition, the interaction between group and pre-MAT scores for post-test MAT [F(1–105) = 2.041, p > .05] and delayed GAT [F(1–105) = 0.771, p > .05], as well as the interaction between group and pretest MAS scores for posttest MAS [F(1–105) = 0.642, p > .05] were not statistically significant. These results indicated that the ANCOVA assumptions for the MAT and MAS scores were met.

Table 2. Descriptive statistical results for assumption of ANCOVA related to MAT and MAS.

Variable	Group	N	Skewness	Kurtosis	Shapiro-Wilk	Levene's test for pretest	Pretest*Group interaction
Pretest for MAT	Experimental	56	−.332	.088	.957		
	Control	53	−.092	−.098	.977		
						F(1–106) = .223	F(1–105) = 2.041
Post-test for MAT	Experimental	56	−.266	−.519	.978		
	Control	53	.245	−.348	.973		
Retention test for MAT	Experimental	56	−.301	−.272	.963	F(1–106) = .223	F(1–105) = .771
	Control	53	.084	−.154	.978		
Pretest for MAS.	Experimental	56	−.246	−.152	.965		
	Control	53	−.017	−.827	.970		
						F(1–106) = 2.587	F(1–105) = .642
Post-test for MAS.	Experimental	56	−.134	−.777	.985		
	Control	53	−.118	−.231	.966		

Note. MAT- Math achievement test, MAS - Math attitude scale.

9. ANALYSIS OF DESCRIPTIVE STATISTICS FOR MAT AND MAS RESULTS

Descriptive statistics obtained from the pretest, posttest, and retention test for the groups' scores on the MAT (Mathematics Assessment Test) and MAS (Mathematics Attitude Scale) are presented in Table 3 and Figure 6. These findings suggest that the experimental group achieved better results on the MAT post-test and MAT memory test than the control group. Moreover, the experimental group exhibited more significant enhancement in MAS post-test scores relative to their pre-test MAS scores, in comparison to the control group.

Table 3. Descriptive statistics for pretest, post-test and retention test scores related to MAT and MAS.

			Pre-test		Post-test		Retention test	
Measure	Group	N	M	SD	M	SD	M	SD
MAT	Experimental	56	37.73	7.42	82.19	10.19	76.25	7.73
	Control	53	38.18	8.13	70.23	8.58	63.34	8.52
M.A.S.	Experimental	56	68.76	12.31	79.11	12.19		
	Control	53	67.59	7.21	70.41	6.67		

III. RESULTS AND DISCUSSION

The study revealed that incorporating GeoGebra into teaching led to significant improvements in student performance compared to traditional textbook-based methods. These findings align with earlier research, which also highlighted the positive influence of dynamic geometry software (DGS) on students' understanding of math concepts and their academic success [14].

Additionally, using GeoGebra in the classroom fostered the development of students' algorithmic skills. By leveraging interactive visualizations and modeling geometric objects, students were able to grasp mathematical algorithms more effectively and apply them in various contexts an essential skill in today's math education landscape [15]. Thirteen weeks after the initial post-test, a retention test showed that students who engaged in collaborative learning with GeoGebra retained knowledge significantly better than those who learned through conventional methods. This finding is consistent with other research showing the benefits of dynamic learning environments like GeoGebra in boosting long-term retention across various math topics. However, some studies, such as Ubuz et al. (2009), did not find significant differences in long-term retention between groups, highlighting the need for further exploration [16].

GeoGebra's dynamic features, such as the ability to drag, resize, and reshape objects, allowed students to actively explore geometric relationships, test their ideas, and make generalizations based on their observations. These capabilities promoted deeper understanding and stronger retention compared to traditional teaching methods. In this study, these interactive features, alongside collaborative learning, played a key role in the improved performance and retention seen in the experimental group [17].

Drawing on theories by Vygotsky and Bruner, the study emphasizes that social interaction and active student involvement are critical for knowledge development. Computer-supported collaborative learning (CSCL) environments offer these opportunities for interaction and engagement, which have been shown in previous studies to enhance learning, problem-solving, and student involvement across subjects. In this case, the gains in achievement and knowledge retention within the experimental group are attributed to students' active participation in discovery-based learning [18]. They used GeoGebra collaboratively with their peers, creating a socially interactive environment where knowledge was constructed together.

Moreover, each small group within the experimental cohort not only shared knowledge gained from using GeoGebra but also refined and restructured their understanding through peer discussions and teacher support. This social interaction within the CSCL environment enabled students to take ownership of their learning, fostering a deeper reconstruction of mathematical concepts [19].

The study also found that using GeoGebra significantly improved students' attitudes toward mathematics when compared to textbook-based teaching. This supports previous research indicating that dynamic geometry programs (DGS) positively influence students' overall perception of math [20]. The enjoyment and engagement experienced by students using GeoGebra, thanks to its visual and interactive nature, sparked their curiosity and made learning more appealing. Additionally, the use of GeoGebra contributed to enhancing students' algorithmic competence, as working with dynamic models and solving problems through this software helped students develop a stronger understanding of mathematical concepts and algorithmic thinking [21].

In summary, this study confirms that using GeoGebra not only boosts students' performance and attitudes toward mathematics but also enhances their algorithmic competence, making it a valuable tool for modern math education [30].

IV. CONCLUSION

The study revealed that integrating information and communication technologies (ICT), like GeoGebra and Desmos, into math education significantly enhances students' ability to understand algorithms. The experimental data showed that students educated with ICT tools achieved higher scores on the Mathematics Aptitude Test (MAT), retained knowledge more effectively, and developed a more favorable outlook on the subject than those who received traditional instruction.

Key findings of the research include:

- Enhanced academic outcomes: The experimental group outperformed the control group on the MAT, demonstrating the beneficial effects of ICT on learning achievements.
- Sustained knowledge over time: Students using ICT for learning showed superior retention of mathematical concepts three months post-experiment, suggesting a lasting benefit of ICT integration.
- Positive shift in attitudes towards math: The engagement with GeoGebra and Desmos led to increased enthusiasm, confidence, and enjoyment in solving math problems among students compared to their peers in the traditional setting.
- These insights underscore the critical role of ICT in enhancing math education quality. Employing tools like GeoGebra and Desmos not only boosts academic performance but also fosters a positive disposition towards math, which is crucial for effective learning.

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Author contribution

All authors made an equal contribution to the development and planning of the study.

Data Availability Statement

Data are available from the authors upon request.

Conflict of Interest

The authors have no potential conflicts of interest, or such divergences linked with this research study.

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