A Meta-Analysis of the Past Decade of Mathematics Learning Based on the Computer Algebra System (CAS)

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Abstract. Hundreds of studies have been found in the literature on mathematics learning supported by the use of the computer algebra system (CAS). However, there are numerous reports with mixed and even contradictory findings. This has the potential to lead to errors in concluding. This meta-analysis study was conducted to test the overall effect size (ES) of CAS-based mathematics learning. This study also aims to analyze the level of variation in individual studies and consider its implications. The ERIC, SAGE, SpringerLink, and Google Scholar databases were examined to achieve relevant research. The search results found 136 related journal articles published between 2010 and 2020. As per the study protocol, 31 articles were eligible, and 36 ES were analyzed. The calculation tool is Comprehensive Meta-Analysis (CMA) software, and the Hedges-g equation is used based on the random-effect model. The analysis results revealed that overall the use of CAS ES had a large positive impact on students’ mathematical abilities (ES = 0.89; standard error 0.08). Moderator analysis shows that CAS’s use is more effective, considering the difference in education level and CAS type. The research implications are discussed and provide important information as a fundamental idea for further meta-analysis studies on CAS's effects.

1. Introduction
Mathematics learning supported by the use of computer algebra systems (CAS) has shown great interest in the last decade. Hundreds of studies have been found and present mathematics lessons that are supported by the use of CAS. In this case, the use of CAS is assumed to help teachers and students learn mathematics and is oriented towards improving students' mathematical abilities.

However, previous individual research investigating these theoretical assumptions has yielded mixed and even contradictory results. How many research results show the advantages of CAS over conventional approaches (e.g., [1]-[3]). Meanwhile, several studies have found that students' mathematical abilities are supported by the use of CAS, not better than the abilities of students taught using conventional approaches [4]-[6]. This difference results in the potential for subjective conclusions to be drawn [7]. While there is a need that educators need accurate information to decide under what conditions the use of CAS achieves a high level of effectiveness.

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In order to cover this gap, the findings of individual studies have been integrated to provide useful information for policymaking [8], [9]. Therefore, a meta-analysis study is needed to provide more generalizable findings compared to individual studies [10], [11]. However, there are no meta-analysis studies that assess the effectiveness of mathematics learning supported by the use of CAS in the literature.

General meta-analyses of the effectiveness of mathematics learning supported by computer use have been carried out [12]-[19]. The meta-analysis study examines the efficacy of computer-based games, visualization, and dynamic geometry software (DGS). However, no specific meta-analysis studies have questioned the overall effectiveness of CAS. Meanwhile, the use of CAS has become a trend for most mathematics teachers today [20]-[23]. Correspondingly, educators need accurate information to decide under what conditions the use of CAS can be more effective. This study aimed to determine the effect of learning as a whole, which is supported by the use of CAS so that it can provide accurate conclusions to educational practitioners in further implementing CAS.

2. Method

2.1. Research design
This study's design is a meta-analysis that combines a group of individual studies to integrate findings [24], [25]. This study begins by determining the inclusion criteria, collecting and coding variables, and statistical analysis [26]-[28]. This research has followed the following stages.

2.2. Inclusion Criteria
Under the research objectives, this study has a standard of feasibility for analysis, namely; (a) in the form of national and international journals; (b) is the result of research on the use of CAS in mathematics learning; (c) publication in at least the last decade (2010-2020); and (d) have sufficient statistical information for the effect size transformation (ES).

2.3. Data collection
Empirical data is collected from online databases that include ERIC (https://eric.ed.gov/), SAGE Publishing (https://journals.sagepub.com/), and Google Scholar (https://scholar.google.com/). The three databases were chosen as locations for data search because they reached all reputable international journals and accredited national journals. However, some journals cannot be accessed because they are paid for. To achieve transparent and quality data selection as suggested by [9], the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) protocol is applied. This work started with identifying 136 data that had been collected from the three databases. Subsequently, based on the screening stage and eligibility, 29 individual studies were included in the analysis. However, there was a study involving more than one comparison group so that 31 ESs were analyzed.

The research instrument was a coding form to extract information from individual studies into numerical data covering study year, education level, sample size, and CAS type. In order to minimize subjectivity, two independent coders were involved. The reliability test used the Cappa Cohen coefficient (κ), which is a vital statistic for testing the level of agreement among coders [29]. Cohen's kappa formula is;

\[ \kappa(7) = \frac{Pr(a) - Pr(e)}{1 - Pr(e)} \]

Where Pr (a) represents an actually observable agreement, and Pr (e) represents a coincidence agreement. A value of 0.85 or greater is predetermined to be considered high. The level of conformity in this study was 0.96. This suggests an almost perfect match between coders. Thus the data in this meta-analysis are reliable.
2.4. Statistic analysis

The unit of analysis in this study is the effect size (ES), which reflects the magnitude of CAS's influence on students' mathematical abilities. The ES transformation uses Hedges' g equation, while the interpretation uses classification [30]; that is, less than 0.2 (negligible), between 0.2 and 0.5 (small effect), between 0.5 and 0.8 (moderate effect), between 0.8, and 1.3 (large effect), and more than 1.3 (very large effect). The estimation method uses a random-effects model because it does not assume that all estimates for the true effect are the same. A heterogeneity test was performed using CMA. The null hypothesis (h0), which states that all study results are the same (homogeneous), is rejected if the p-value is <0.05, which means that the ES between studies or study groups is different or may not measure the same parameters [31].

3. Result and Discussion

3.1. Overall Analysis

First, this study was conducted to determine the magnitude of the overall effect of CAS use. Figure 1 presents the distribution and interpretation of ES by classification [30].

![Figure 1. Interpretation of ES](image)

Figure 1 illustrates the inconsistent ES use of CAS, which reflects the study variable's effect on students' mathematical abilities. Table 1 shows the comparison of the research results according to the estimation method.

| Model          | N   | Hedges’s g | Standard Error | 95% Confidence Interval | Q     | P     | Decision   |
|----------------|-----|------------|----------------|-------------------------|-------|-------|------------|
| Fixed-effects  | 31  | 0.86       | 0.04           | 0.76 - 0.95             | 100.99| 0.00  | Reject H0  |
| Random-effects | 31  | 0.89       | 0.08           | 0.71 - 1.06             |       |       |            |

Table 3 shows that the p-value was found to be <0.05, which means that the ES distribution is heterogeneous. Therefore, the estimation model fits the random-effect model. The challenge in meta-
analysis research is to avoid publication bias, namely journals' tendency to only publish significant articles, leading to over-representation [31], [32]. Therefore, the study funnel plot in Figure 2 was included to check for publication bias. Resistant to publication bias if the ES studies are spread symmetrically across [31]. If the 31 ES studies were not completely symmetrical, then the Rosenthal fail-safe N (FSN) statistic was used to check for publication bias. The formula used is $N = \frac{N}{5k + 10}$, where $N$ is the FSN value, and $k$ is the number of studies [33]. If the calculation result is greater than 1, it means that this study's results are resistant to publication bias. Figure 2 presents the research funnel plot.

Figure 2. Funnel study plot

Figure 2 shows that the ES is not entirely symmetrical in the center of the funnel plot. From the calculation result, the $N$ value is calculated as 2652. The calculation result of $2652 / (5 \times 31 + 10)$, is $16.02 > 1$. This means that the studies included in this analysis are resistant to publication bias. Thus, no study was lost or needed to be added to the analysis because of publication bias.

According to the random-effects model, the overall ES of this study was estimated at 0.89, which means that CAS use had a high impact on students' abilities. This result is supported by a previous meta-analysis conducted by [18] on the effect of computer visualization on mathematics learning achievement using (ES = 0.81). Results finding higher ES were reported in the study [13]. They found ES = 1.02 when analyzing 587 individual studies of the overall impact of a dynamic geometry software (DGS). Furthermore, [14] reported ES 0.79 when analyzing 26 individual computer software studies in mathematics learning. This study's results almost similarly reflect the overall trend of computer use in learning, including CAS [34], even though the samples and study periods are different.

3.2. Results of Analysis of Mediator Variables
The results included in the meta-analysis show a heterogeneous distribution so that the mediator variables which are considered to influence the relationship between the dependent and independent variables should be investigated [35]. Table 2 below is a summary of the analysis results.
Table 2: Results of Mediator Variable Analysis

| Mediator Variable | Group               | N   | Hedge's g | Heterogeneity (Qb) | df(Q) | P    | Decision     |
|-------------------|---------------------|-----|-----------|-------------------|-------|------|--------------|
| Publication year  | 2010-2014           | 7   | 0.76      |                   |       |      |              |
|                   | 2015-2017           | 9   | 0.89      | 1.17              | 2     | 0.56 | Failed to Reject H0 |
|                   | 2018-2020           | 15  | 0.90      |                   |       |      |              |
| Educational stage | Primary school      | 3   | 1.24      |                   |       |      |              |
|                   | Junior high school  | 6   | 1.30      | 31.32             | 4     | 0.00 | Reject H0    |
|                   | Senior high school  | 7   | 0.65      |                   |       |      |              |
|                   | Vocational high school | 4  | 0.54      |                   |       |      |              |
|                   | College             | 11  | 0.87      |                   |       |      |              |
| Sample size       | 30 or less          | 16  | 0.93      | 40.52             | 0.99  | 0.32 | Failed to Reject H0 |
|                   | 31 or more          | 15  | 0.82      |                   |       |      |              |
| CAS type          | Algebrator          | 4   | 1.25      |                   |       |      |              |
|                   | Autograph           | 4   | 0.65      |                   |       |      |              |
|                   | Flash               | 3   | 0.80      |                   |       |      |              |
|                   | Hawgent             | 2   | 1.09      | 29.05             | 7     | 0.00 | Reject H0    |
|                   | Maple               | 6   | 0.71      |                   |       |      |              |
|                   | Matlab              | 3   | 0.94      |                   |       |      |              |
|                   | Microsoft Math      | 4   | 0.60      |                   |       |      |              |

The results of the moderator variable analysis in Table 2 show that CAS use was associated with differences in education level ($Q = 31.32; P < 0.05$) and CAS type ($Q = 29.05; P < 0.05$). Based on differences in education levels, CAS is more effectively used in primary and junior secondary schools. This result differs from a previous meta-analysis of the effect of mathematics software and reports that educational attainment differences do not change the effect size of the studies [19]. Based on the CAS type, it was found that the algebrator software was more effective than other types. This is presumably due to differences in learning material. However, a more comprehensive meta-analysis is needed to verify these findings.

Although previous studies have shown that differences in sample sizes affect the ES of the study [26], this study found the opposite. This surprised us because it was different from the previous assumption that CAS was effective in a small sample. Furthermore, based on the study year, there was no difference in ES between study groups. This finding differs from previous studies in that the early years of computer use had more impact on students [12]. Thus, the students involved as an individual study sample were not affected by the novelty effect of using CAS.

4. Conclusion
The results of the analysis show that the use of CAS has a large positive effect on students' mathematical abilities. The moderator analysis revealed that the use of CAS was more effective considering the differences in education level and the type of CAS used. This study examines the implications for the use of CAS and offers recommendations for future research. However, these findings were only supported by studies of individuals who were eligible for analysis. Many other studies are similar but do not inform the statistical data needed to transform effect sizes. Subsequent individual studies of the effects of CAS need to report complete statistical data. Besides, to provide a more comprehensive picture, it is necessary to conduct a meta-analysis in the future, where studies with comparisons between countries, differences in treatment duration, and perhaps student characteristics are the moderator variables.

5. Acknowledgments
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6. References

[1] Wijaya T T Ying Z and Purnama A, 2020 The Empirical Research Of Hawgent Dynamic Mathematics Technology Integrated Into Teaching Fraction In Primary School *J. Cendekia J. Pendidik. Mat.* **4**, 1 p. 144–150.

[2] Rahmawati R and Khaerani K, 2019 Efektivitas penggunaan maple terhadap hasil belajar aljabar linear II mahasiswa semester IV prodi pendidikan matematika universitas muslim maros *J. Equal.* **2**, 1 p. 18–22.

[3] Haswati D and Nopitasari D, 2019 Implementasi Bahan Ajar Persamaan Differensial dengan Metode Guided Discovery Berbantuan Software Mathematica untuk Meningkatkan Pemahaman Konsep *J. Gantang* **2**, 2 p. 97–102.

[4] Suwarno, 2016 Penerapan Model Tutorial Berbantuan Mathematica Untuk Meningkatkan *KALAMATIKA J. Pendidik. Mat.* **1**, 1 p. 47–58.

[5] Hukom F F Mataheru W and Laamena C M, 2020 Perbedaan hasil belajar siswa kelas viii smp menggunakan model problem based learning ( PBL ) berbantuan aplikasi s wishmax dan model pembelajaran konvensional pada materi prisma dan limas the difference in learning outcomes of VIII grade students of SMP *J. Pendidik. Mat. Unpatti* **1**, 1 p. 1–6.

[6] Petrina H U, 2019 Penerapan Pembelajaran Matematika Menggunakan Software Algebrator untuk Meningkatkan Kemampuan Berpikir Kritis Siswa *Disk. Panel Nas. Pendidik. Mat.* **0812**, 50 p. 25–30.

[7] Franzen M, 2020, Meta-analysis, in *Encyclopedia of Personality and Individual Differences*, H. V. Zeigler and T. . Shankelford, Eds. (Springer, Cham), p. 5925.

[8] Siddaway A P Wood A M and Hedges L V., 2019 How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses *Annu. Rev. Psychol.* **70**, 1 p. 747–770.

[9] Pigott T D and Polanin J R, 2020 Methodological Guidance Paper: High-Quality Meta-Analysis in a Systematic Review *Rev. Educ. Res.* **90**, 1 p. 24–46.

[10] Demirel M and Dağyar M, 2016 Effects of Problem-Based Learning on Attitude: A Meta-analysis Stud *EURASIA J. Math. Sci. Technol. Educ.* **12**, 8 p. 2115–2137.

[11] Tamur M Jehadus E Nendi F Mandur K and Murni V, 2020 Assessing the effectiveness of the contextual teaching and learning model on students’ mathematical understanding ability: a meta-analysis study J. Phys. Conf. Ser. *1657*, 1 p. 012067.

[12] Bayraktar S, 2001 A Meta-analysis of the Effectiveness of Computer-Assisted Instruction in Science Education *J. Res. Technol. Educ.* **34**, 2 p. 173–188.

[13] Chan K K and Leung S W, 2014 Dynamic geometry software improves mathematical achievement: Systematic review and meta-analysis *J. Educ. Comput. Res.* **51**, 3 p. 311–325.

[14] Turgut S and Temur Ö D, 2017 The effect of game-assisted mathematics education on academic achievement in Turkey: A meta-analysis study *Int. Electron. J. Elem. Educ.* **10**, 2 p. 195–206.

[15] Yesilyurt M Dogan M and Acar S, 2019 The Meta-Analysis of the Effect of Computer Aided Instruction on Student Attitudes in Science and Mathematics *J. Prim. Educ.* **1**, 2 p. 57–69.

[16] Kim N J Belland B R Lefler M Andreasen L Walker A and Axelrod D, 2020 Computer-Based Scaffolding Targeting Individual Versus Groups in Problem-Centered Instruction for STEM Education: Meta-analysis *Educ. Psychol. Rev.* **32**, 2 p. 415–461.

[17] Chen C H Shih C C and Law V, 2020 The effects of competition in digital game-based learning (DGBL): a meta-analysis *Educ. Technol. Res. Dev.* **68**, 4 p. 1855–1873.

[18] Turgut I G and Turgut S, 2018 The effects of visualization on mathematics achievement in reference to thesis studies conducted in Turkey: A meta-analysis *Univers. J. Educ. Res.* **6**, 5 p. 1094–1106.

[19] Tamur M Juandi D and Kusumah Y S, 2020 The Effectiveness of the Application of Mathematical Software in Indonesia: A Meta-Analysis Study *Int. J. Instr.* **13**, 4 p. 867–884.
[20] Tamur M Kusumah Y S Juandi D Wijaya T T Nurjaman A and Samura A O, 2021 Hawthorne effect and mathematical software based learning: A meta- analysis study J. Phys. Conf. Ser. 1806, 1 p. 012072.

[21] Kusumah Y S Kustiawati D and Herman T, 2020 The Effect of GeoGebra in Three-Dimensional Geometry Learning on Students’ Mathematical Communication Ability Int. J. Instr. 13, 2 p. 895–908.

[22] Juandi D Kusumah Y S Tamur M et al., 2021 The Effectiveness of Dynamic Geometry Software Applications in Learning Mathematics: A Meta- Analysis Study Int. J. Interact. Mob. Technol. 15, 02 p. 18–37.

[23] Tamur M Sennen E and Men F E, 2018 Konsep Dasar Matematika Berbasis CAS dan DGS STKIP St. Paulus Ruteng.

[24] Kusumah Y S Kustiawati D and Herman T, 2020 The Effect of GeoGebra in Three-Dimensional Geometry Learning on Students’ Mathematical Communication Ability Int. J. Instr. 13, 2 p. 895–908.

[25] Tamur M and Juandi D, 2020 Effectiveness of Constructivism Based Learning Models Against Students Mathematical Creative Thinking Abilities in Indonesia: A Meta-Analysis Study Pervasive Heal. Pervasive Comput. Technol. Healthc. 1 p. 107–114.

[26] Tamur M and Juandi D, 2020 Effectiveness of Constructivism Based Learning Models Against Students Mathematical Creative Thinking Abilities in Indonesia: A Meta-Analysis Study Pervasive Heal. Pervasive Comput. Technol. Healthc. 1 p. 107–114.

[27] Tamur M and Juandi D, 2020 Realistic Mathematics Education in Indonesia and Recommendations for Future Implementation: A Meta-Analysis Study J. Teor. dan Apl. Mat. 4, 1 p. 17–27.

[28] Tamur M and Juandi D, 2020 Effectiveness of Constructivism Based Learning Models Against Students Mathematical Creative Thinking Abilities in Indonesia: A Meta-Analysis Study Pervasive Heal. Pervasive Comput. Technol. Healthc. 1 p. 107–114.

[29] Tamur M and Juandi D, 2020 Realistic Mathematics Education in Indonesia and Recommendations for Future Implementation: A Meta-Analysis Study J. Teor. dan Apl. Mat. 4, 1 p. 17–27.

[30] Pigott T D, 2012 Advances in Meta-Analysis Springer New York Dordrecht Heidelberg London.

[31] Susanti N Juandi D and Tamur M, 2020 The Effect of Problem-Based Learning ( PBL ) Model On Mathematical Communication Skills of Junior High School Students – A Meta-Analysis Study JTAM (Jurnal Teor. dan Apl. Mat. 4, 2 p. 145–154.

[32] McHugh M L, 2012 Lessons in biostatistics interrater reliability: the kappa statistic Biochem. Medica 22, 3 p. 276–282.

[33] Cohen J, 1988 Statistical power analysis for the behavioral sciences 111, 479.

[34] Borenstein M Hedges L V Higgins J P T and Rothstein H R, 2009 Introduction to Meta-Analysis January A John Wiley and Sons, Ltd., Publication.

[35] Suparman Juandi D and Tamur M, 2021 Review of problem-based learning trends in 2010-2020: A meta-analysis study of the effect of problem-based learning in enhancing mathematical problem-solving skills of Indonesian students J. Phys. Conf. Ser. 1772, 1 p. 012103.

[36] Mullen B Muellerleile P and Bryant B, 2001 Cumulative meta-analysis: A consideration of indicators of sufficiency and stability Personal. Soc. Psychol. Bull. 27, 11 p. 1450–1462.

[37] Nurjanah Latif B Yuliardi R and Tamur M, 2020 Computer-assisted learning using the Cabri 3D for improving spatial ability and self-regulated learning Heliyon 6, 11 p. e05536

[38] Arik S and Yilmaz M, 2020 The effect of constructivist learning approach and active learning on environmental education: A meta-analysis study Int. Electron. J. Environ. Educ. 10, 1 p. 44–84.