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**Review Article**

# A meta-analysis of the effectiveness of mobile supported collaborative learning

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## ABSTRACT

The objective of this meta-analysis study is to investigate learning results under mobile supported collaborative learning (MSCL). Robust Bayesian meta-analysis was applied to eleven studies from Scopus, Web of Science, and ERIC databases. The results reveal that MSCL has a modest but favorable effect generally (d = 0.26, 95% confidence interval [CI] [–0.34, 0.89]). Studies revealed substantial degrees of heterogeneity (τ = 0.556, 95% CI [0.305, 1.027], implying that contextual elements might influence the efficacy of MSCL. Moderator analyses showed that the MSCL was more successful at the high school level and had a greater and consistent influence especially on student motivation. Moderate publication bias was identified. These results highlight the value of MSCL as a potential improvement tool in education but suggest that its effectiveness may vary by context. Future research should examine in more detail the specific factors that increase or decrease the effectiveness of MSCL. Educators and policy makers should consider the potential benefits and limitations of this approach when implementing MSCL.

**Keywords:** mobile supported collaborative learning, robust Bayesian meta-analysis, learning outcomes, collaborative learning

## INTRODUCTION

The fast spread of technology in the 21st century has brought about notable developments in the realm of education. Particularly the spread of mobile devices presents fresh chances in education and changes the nature of learning environments (Crompton & Burke, 2018). Since it allows students work anywhere and at any moment by merging traditional learning approaches with mobile technologies, mobile supported collaborative learning (MSCL) has evolved into a creative solution in this context (Fu & Hwang, 2018).

MSCL offers the social and cognitive advantages of group learning (Sung et al., 2017) together with the portability and connection of mobile devices. This method motivates students to participate actively, so fostering critical thinking ability and a greater knowledge depth (Johnson & Johnson, 2009). Furthermore demonstrated in several studies by MSCL are students' increased motivation, improved academic performance, and development of their 21st century skills (Lee & Lai, 2024; Lin et al., 2021). The literature does, however, provide some contradictions on the efficiency of MSCL. While some studies show notable favorable effects of MSCL (Huang et al., 2020; Zhang & Hwang, 2023) others show less clear or conflicting findings (Tiantian et al., 2024). Furthermore documented have been various obstacles to MSCL deployment including technical problems, student preparedness, and teacher skills (Cerratto Pargman et al., 2018).

In this context, the current study is a meta-analysis that aims to comprehensively assess the overall impact of MSCL on learning outcomes. The main objectives of the study are the following:

- to determine the overall effect size of MSCL,
- to examine the distribution of effect sizes,
- to determine the level of heterogeneity between studies,
- assessing possible broadcast bias, and
- investigate the role of moderator variables (e.g., level of education and type of learning outcome) on the effectiveness of MSCL.

This meta-analysis will synthesize the available evidence on the effectiveness of MSCL, helping to identify under what conditions and for which groups of students this approach is most effective. This information will guide educators and policy makers in the effective implementation of MSCL and will inform future research efforts. Furthermore, by identifying current research gaps in the field of MSCL, this study will offer new perspectives for future work. Given the growing importance of MSCL and the rapidly evolving nature of educational technologies, this meta-analysis is critical to the development and implementation of effective learning strategies in the digital age. The results of this study will provide valuable insights for educational researchers, practitioners and policy makers, contributing to improving educational practices and increasing student achievement.

## LITERATURE REVIEW

### Mobile Supported Collaborative Learning

Considering the increasing use of mobile devices, it is inevitable that they will be used in the field of education. Thanks to the ubiquitous accessibility of mobile devices, learners can access educational content from anywhere. In addition, collaboration skills are among the 21st century skills. Using the collaboration features of mobile devices will provide added value to education.

MSCL is a learning process based on both mobile learning access to education from anywhere and collaboration (Fu & Hwang, 2018; Liu, 2015). Collaborative learning, defined as an approach to education that involves the joint intellectual efforts of students or teachers together, has long been recognized for its positive effects on learning outcomes (Van der Linden et al., 2000). When integrated with mobile technologies, new dimensions of interaction and collaboration between learners emerge.

The rapid development of mobile devices such as smartphones and tablets and the proliferation of 4G/5G networks have further increased the potential of mobile learning (Huang et al., 2020). These technical developments have removed the restrictions of conventional classroom environments by allowing students to participate in group projects anywhere and at any moment.

Numerous studies have demonstrated MSCL's performance in several learning contexts. For example, according to Lin et al. (2021), mobile-based collaborative learning improved students' English hearing and reading comprehension skills as well as their knowledge of fitness-specific challenges. The paper stressed the necessity of context-sensitive ubiquitous learning in providing interactive learning environments enhancing learning efficacy and self-efficacy.

Lee and Lai (2024) proposed a gamified collaborative arguing technique in mathematics education using mobile devices. Their studies revealed that this approach improved students' tendency to work in groups as well as their enthusiasm for learning and their mathematical learning skills. Gamification's elements drove pupils to participate more actively in mathematical disputes inside the collaborative learning process. MSCL offers advantages beyond mere academic success. Reviewing mobile computer supported collaborative learning (mCSCL) in mathematics education, Bringula and Atienza (2023) discovered MCSL improved students' social skills, attitudes, and mathematical ability, they found. The study also highlighted mCSCL's ability to design innovative, welcoming, and creative learning settings that might enable students to overcome arithmetic fear.

Still, using the mCSCL brings significant challenges. Huang et al. (2020) noticed several issues on cooperative mobile learning for natural science courses. These cover issues with usability, device unfamiliarity, and difficulty tracking student activities. They stressed the need for appropriate instruments and strategies for conquering challenges and maximizing the benefits of mobile cooperative learning. An important aspect of successful MSCL implementation is the choice of collaborative platforms. Google Docs has emerged as a popular tool to facilitate collaborative activities in mobile learning environments (Huang et al., 2020; Lin et al., 2021). Its simplicity, ease of access and excellent version control make it particularly suitable for educational purposes.

The combination of MSCL with other creative ideas such as gamification (Lee & Lai, 2024) and context-aware learning (Lin et al., 2021) promises to increase its efficacy even further. These combinations can help with some of the engagement and motivation issues usually related to mobile learning. In essence, MSCL reflects a significant advancement in educational technology since it presents new ways to inspire student connection, participation, and knowledge generation. Although challenges still exist, more and more research shows that MSCL, applied purposefully, may significantly enhance the learning process and outcomes in many different educational settings.

## The Effect of Mobile Supported Collaborative Learning on Students Outcomes

The impact of MSCL on student outcomes has been a topic of growing interest in educational research. This impact covers a number of areas.

### *Academic achievement*

Numerous research have shown how well MSCL improves the academic performance of kids. Huang et al. (2020) investigate collaborative mobile learning for elementary school natural science classes. Students who participated in mobile-based collaborative learning showed noticeably superior learning results than those who used more traditional learning environments. In post-test results, the experimental group applying the collaborative learning strategy outperformed the control group, therefore demonstrating higher knowledge acquisition and retention. In the study of Fabian et al. (2018), MSCL activities related to mathematics courses were applied to primary school students. As a result of the study, an increase in students' mathematics achievement was observed.

In the realm of language education, Lin et al. (2021) looked at how English hearing and reading comprehension responded to mobile-based collaborative learning. Their studies show that both group and individual mobile learning approaches improved student performance; yet, the group that applied collaborative learning showed better development, especially in regard to information important to certain sectors. This suggests that MSCL can increase knowledge particular to a given topic in addition to language skills.

Additionally, ideas that come from MSCL are used in the field of teaching numbers. By using mobile technology and gamified collaborative argumentation methods, Lee and Lai (2024) made math lessons more like games by using mobile technology. Based on their study, they found that students who used this creative method had much better math skills than students who used more traditional teaching methods. In addition, according to Tiantian et al. (2024), collaborative mobile learning does not have a statistically significant effect directly on academic performance.

### *Cognitive load and learning efficiency*

Examining the efficacy of any learning strategy requires one to take cognitive load into great account. Students that employed collaborative mobile learning reported less cognitive load than those engaged in solitary learning, according to Huang et al. (2020). By allowing students to concentrate more on understanding and applying ideas than on controlling the learning environment, this lowered cognitive load could help to enable more effective learning processes.

Jiang and Zhang (2020) examined the effect of providing explicit socialization activities to previously unfamiliar students on cognitive load in MSCL environments. The results showed that the group given explicit socialization activities experienced lower levels of cognitive load compared to the implicit socialization group. In particular, the explicit socialization group experienced significantly less external cognitive load. These findings suggest that familiarity and social ties between learners reduce external cognitive load by enabling more efficient allocation of cognitive resources to learning tasks, thereby reducing overall cognitive load.

The results of Reychav and Wu (2016) offer important implications in the context of cognitive load theory. Research findings show that interaction with mobile technologies and peers increases cognitive load as task complexity increases. Especially in high cognitive complexity tasks, the use of interactive mobile applications and collaborative work negatively affected the performance of the participants by diverting their cognitive resources away from the problem solving process. This suggests that in complex tasks, individuals should primarily focus their cognitive resources on understanding and solving the problem, and that technology and group interaction may create additional cognitive load and hinder the learning process. Therefore, in the design of MSCL environments, a careful balance between task complexity and technology and group interaction is critical to optimize learning effectiveness.

### *Motivation, engagement, and attitudes*

They are more involved and motivated now that MSCL is in place. Lee and Lai (2024) found that gamified mobile collaborative learning tools made students much more interested in learning math. Adding game-like features to group learning made the classroom more interesting and encouraged students to take part in math debates more. Fabian et al. (2018) organized collaborative learning activities with tablets. In the study, it was stated that students' attitudes towards mathematics courses were positive. According to the study by Salhab and Daher (2023), MSCL projects with twenty-five third and fourth year students of the faculty of arts and educational sciences in the department of technology education enrich students' participation, increase their self-confidence and keep their interest alive. This self-confidence and interest also motivates their emotional engagement. Comparably, students engaged in mobile-based collaborative learning showed better self-efficacy and favorable opinions of the learning process, according to Lin et al. (2021). This improved attitude and higher degree of satisfaction could help to explain superior long-term learning results and ongoing involvement.

The study by Nikou and Economides (2021) included fifty-one pupils from an urban public high school in Europe. Using QR codes, the students said they like these spatial assessment activities in which they completed assessment assignments. They also claimed that mobile gadgets gave them independence and encouraged them to feel motivated and involved. Students' impressions of their degrees of autonomy, competency, and relatedness were found to be much improved by the mobile-based formative assessment activities, hence raising their degrees of intrinsic motivation. Similarly, according to Tiantian et al. (2024), collaborative mobile learning positively affects student motivation.

Lin et al. (2021) also found that students were more motivated and involved when they used mobile-based groups learning to learn a language. Students are more likely to be interested in and participate in learning opportunities when MSCL is interactive and easy to use on mobile devices. According to the results of the study on the use of MSCL by pre-service teachers conducted by Liu (2015), it was determined that pre-service teachers shared their experiences related to the practicum and the opinions of pre-service teachers were positive.

### *Social and cooperative skills*

MCSCL also changes how friendly students are and how willing they are to work on projects with others. As an example, Bringula and Atienza (2023) said that it helps students get along with others and be more open to doing group work. According to the study, mCSCL is a good place to improve your communication and group work skills, which are useful at school and at work.

The findings of Tiantian et al. (2024) reveal that collaborative mobile learning has a significant and positive impact on social interaction. By testing the hypothesis, researchers found that collaborative mobile learning significantly affects social interaction in pre-college education. According to the results of the analysis, the original sample value was 0.754, indicating a strong positive effect. These findings suggest that collaborative mobile learning environments encourage interaction and strengthen social connections among students. The researchers suggest that mobile technologies can be used as an effective tool to increase social interaction in the learning process.

Lee and Lai (2024) looked into how students felt about using gamified mobile collaborative learning to help them work together. After looking at the findings, it was clear that big gains were made. This strong desire to work together may have effects beyond school.

### *Difficulties and challenges*

Although MSCL appears to have a generally favorable effect on student results, there are certain difficulties to be mentioned. Huang et al. (2020) find obstacles including usability concerns, device inexperience, and challenges tracking student activity. If these elements are not properly handled, they could possibly reduce the efficacy of MSCL. According to Reychav and Wu (2016), challenges include cognitive load management, optimization of interaction level, effective management of group dynamics, ensuring ease of use of technology, appropriate balance between individual and collaborative learning, and designing for task complexity. In particular, mobile technologies and group interactions in complex tasks may cause excessive cognitive load, which may negatively affect learning performance. Furthermore, the fact that interactive applications do not always produce better results and sometimes have lower perceived ease of use than basic applications are important considerations in the design process. Overcoming these challenges requires educators and designers to strike a delicate balance between task complexity, technology interactivity and level of collaboration. Achieving this balance is critical to increase the effectiveness of MSCL applications and optimizing learning outcomes.

Cerratto Pargman et al. (2018) examined the use of tablet computers as a collaborative learning tool in the classroom environment and emphasized the complexities that arise in this process. In particular, teachers and students need to develop multiple instrumental mediations for tablets to emerge as a collaborative tool. The creation of these mediations depends on teachers' ability to integrate technology into their teaching practices and students' ability to use these tools effectively in collaborative learning processes. It was also emphasized that tablets should be designed in a tool ecology that would work in harmony with other classroom technologies. These findings suggest that the successful implementation of MSCL requires careful consideration of complex pedagogical and technological factors rather than just the provision of technology.

According to the study of the literature, MSCL has been used in many fields and in several educational environments. MSCL seems to improve many learning outcomes including academic performance, motivation, teamwork ability, and self-efficacy. On the efficiency of MSCL, meantime, there are also conflicting findings and various difficulties applying this method. Existing research suggests that the effectiveness of MSCL may vary according to context, implementation method and student characteristics. However, there is a gap in systematically examining these variations and quantitatively assessing the overall effectiveness of MSCL.

This meta-analysis aims to assess the overall impact of MSCL on learning outcomes, examine the distribution of effect sizes, determine the level of heterogeneity across studies, and identify potential publication bias. It also looks at MSCL's performance under moderator variables (like kind of learning outcome and degree of education), trying to find how precisely By enabling the identification of under which conditions and for which groups of students MSCL is most successful, this extensive study will direct forthcoming research and implementation projects. This work aims to greatly increase the body of knowledge by consolidating the present data on the effectiveness of MSCL and highlighting research need in this field.

## METHODOLOGY

As a meta-analysis, the current study is being done with the intention of determining how effective MSCL is. Meta-analysis, which is a methodical technique, is a strategy that helps produce an overall impact magnitude by combining the data of various studies that have been conducted on a specific subject (Borenstein et al., 2021). With the help of a thorough Bayesian meta-analysis approach, this paper investigated the impact that MSCL has on learning outcomes (Maier et al., 2023). Robust Bayesian meta-analysis solves possible issues such heterogeneity and publication bias, more successfully than conventional meta-analysis methods (Gronau et al., 2017). This method could help to more faithfully provide findings in model comparisons and better depict uncertainty in parameter estimations (Bartoš et al., 2022). In this section, the research questions, literature review process, inclusion and exclusion criteria, coded moderators and data analysis methods will be explained in detail. In addition, the statistical models used in meta-analysis and the software tools used in the application of these models will also be specified.

### Research Questions

1. What is the total effect size of MSCL studies?
2. What is the effect size distribution of the studies?
3. What is the level of heterogeneity in the studies?
4. What is the level of publication bias in the studies?
5. How are the effect sizes of the studies according to moderator variables?

### Search Process

Within the scope of the research, three important electronic databases widely used in the field of education were searched: Scopus, Web of Science (WoS), and ERIC. These databases contain recent and comprehensive studies on educational technologies and learning methods. The search process was limited to studies published from 2015 onwards, reflecting the period when the widespread use of mobile technologies in education increased significantly.

The following search query was used in all databases: (effectiveness OR efficacy OR impact OR outcome*) AND (mobile OR "m-learning" OR "mobile learning" OR "mobile-assisted" OR "mobile-based" OR smartphone* OR tablet*) AND ("collaborative learning" OR "cooperative learning" OR "group learning" OR "peer learning" OR "team learning").

This search query aims to comprehensively identify studies examining the effectiveness of MSCL.

399, 379 and 192 studies were retrieved from Scopus, WoS, and ERIC databases, respectively, totaling 970 studies (**Figure 1**).

In the first stage, these studies were imported into reference management software and 293 duplicate studies were eliminated. The titles and abstracts of the remaining 677 articles were reviewed, and specific inclusion and exclusion criteria were applied. Inclusion criteria included that the study was published in 2015 or later, was written in English, was published in peer-reviewed journals, and was an empirical study examining the effectiveness of MSCL.

Exclusion criteria (as shown in **Table 1**) were studies that did not provide primary data sources such as meta-analyses, review articles and systematic reviews; studies that focused only on mobile learning tools or only on collaborative learning; and studies whose full text was not accessible. As a result of the application of these criteria, 56 studies were selected for detailed review. The full texts of these studies were obtained and subjected to a detailed review. At this stage, in addition to the above criteria, the presence of statistical data required for meta-analysis (e.g., mean, standard deviation or t-test results required for effect size calculations) was checked. Single-group studies or studies that did not provide comparison data were also excluded at this

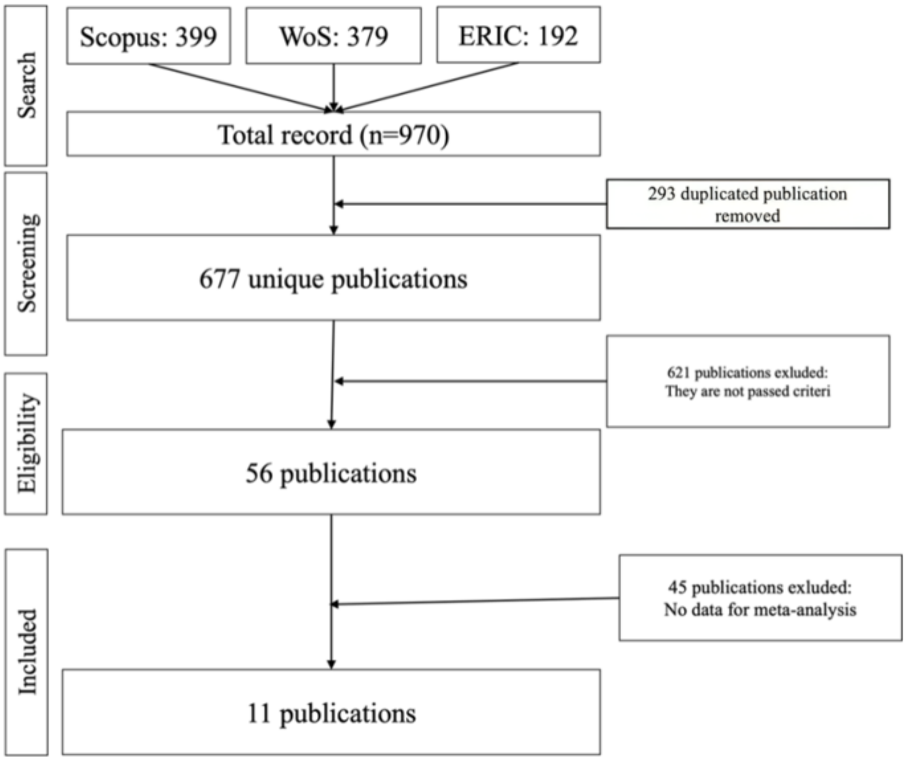


**Figure 1.** Data collection process (created by the authors)

**Table 1.** Inclusion and exclusion criteria

| Criteria | Inclusion | Exclusion |
|---|---|---|
| Publication type | Peer-reviewed journal articles | Meta-analyses, literature reviews, systematic reviews, conference proceedings, & book chapters |
| Publication year | Published from 2015 onwards | Published before 2015 |
| Language | English | Non-English languages |
| Study design | Empirical studies with quantitative data & studies with comparison groups | Qualitative studies & single group studies without comparison data |
| Focus | Studies examining the effectiveness of mobile-supported collaborative learning | Studies focusing solely on mobile learning tools & studies focusing solely on collaborative learning without mobile support |
| Outcome measures | Studies reporting quantitative outcomes (e.g., academic achievement, motivation, & skills) | Studies without clear quantitative outcome measures |
| Statistical data | Studies providing sufficient statistical data for effect size calculation (e.g., means, standard deviations, & t-test results) | Studies lacking necessary statistical data for meta-analysis |
| Accessibility | Full-text articles accessible to researchers | Articles with inaccessible full texts |

stage. After detailed review, 11 studies that met all inclusion criteria and provided the necessary statistical data were included in the meta-analysis. This systematic search and selection process increases the quality and reliability of meta-analysis as well as ensuring study reproducibility and transparency.

## Coded Moderators

Several moderator variables that can possibly affect the efficacy of MSCL were coded in this meta-analysis. These factors helped to explain variations across studies and to grasp under which circumstances MSCL would be more successful. The following moderators were coded:

1. Country: The country where the studies were conducted (e.g., Taiwan, Iran, China, and Malaysia).
2. Subject area (issue): The academic field or issue MSCL was applied (e.g., gamified mobile collaborative learning, English, information and communication technology (ICT), problem-posing method, story

writing, mathematics learning, writing skills). Participants' educational level and traits-that is, those of fifth-grade students, university students, elementary students, junior high school students, post-intermediate ESP learners-that is, their character. Applied in the research, dependent variables or measuring tools include mathematics learning accomplishment, intrinsic motivation, extrinsic incentive, inclination of cooperation performance, learning performance, self-efficacy, cognitive load. This kind of mobile technology is being used (such as a tablet or smartphone). Though **Table 1** does not specifically show this information, the emphasis of the studies helps one to deduce it.

3. Collaborative learning strategy: Collaborative learning methods applied (e.g., gamified collaborative learning, problem-posing-based collaborative learning). Although this information is not directly mentioned in **Table 1**, it can be inferred from the focus of the studies.

These moderators were used in subgroup analyses to understand the factors influencing the effectiveness of MSCL, such as the level of education and types of measurement, which form a sufficient group.

### Data Analysis

Robust Bayesian meta-analysis approach helped to evaluate the effect of MSCL. This method provides more flexible and reliable results than traditional meta-analysis methods in the framework of possible problems including heterogeneity and publication bias.

Analyzes using JASP version 0.19. Cohen's (1988) d was selected as the better effect size metric with respect to its universal applicability and interpretability in educational research.

Markov Chain Monte Carlo simulations were used to estimate posterior distributions. In this context, a total of 10,000 samples were obtained by creating four separate chains, each containing 2,500 samples. In order to stabilize the chains, the first 2,000 iterations were reserved as burn-in period. For the adaptation phase, 500 iterations were used.

In order to evaluate the convergence and stability of the chains, the R-hat statistic was used and a threshold value of 1.05 was set. This threshold value indicates that the chains are sufficiently mixed and provide reliable predictions. Furthermore, the effective sample size is set to 500 to ensure that the posterior distributions are estimated with sufficient precision.

The model is built using a hierarchical structure with three levels: within-study variance, between-study variance and overall average effect. This hierarchical structure makes it possible to obtain more accurate estimates by modeling heterogeneity between studies.

We evaluated and corrected for publication bias using the PET-PEESE approach. By modeling the link between standard error and effect magnitude, this technique helps to detect and correct any biases. Bayes factors (BFs) were used for model comparisons and parameter estimates. This approach allows assessing the relative strength of evidence of different models and measuring the precision of parameter estimates. A seed value of 27 was used for the random number generator to ensure reproducibility of the analyses. We also enabled the option to rebalance the component probabilities in case of model failure, which makes the model more robust and reliable.

This robust Bayesian meta-analysis approach enables us to derive more thorough and trustworthy conclusions regarding the efficiency of MSCL. It especially enables us to evaluate the possible consequences of publication bias, more precisely describe the uncertainty of impact size, and represent heterogeneity in detail.

## FINDINGS

In this section, the results of the meta-analysis of MSCL effectiveness will be presented. The analyses are structured to answer the identified research questions. First, descriptive characteristics of the included studies will be presented, followed by findings on overall effect size, heterogeneity and publication bias. We will then show studies on the impact of moderate factors (learning results and educational degree). Every discovery will be backed by pertinent graphs and tables and be momentarily explained. These results seek to present a whole picture of MSCL's efficacy as well as to pinpoint the circumstances under which this method

**Table 2.** Descriptive information

| Author | Topic | Sample | Duration | Measure |
|---|---|---|---|---|
| Aghajani and Adloo (2018) | Writing skills | Post-intermediate ESP learners at university | 8 week | Writing skills |
| Chang et al. (2018) | Geography | Sixth grader | No info | Knowledge |
| Sung et al. (2016) | Problem-posing strategy | Fifth graders in an elementary | 2 weeks | Learning achievement<br>problem-posing group learning self-efficacy |
| Hanafi et al. (2016) | ICT | First-semester social science majors | No data | Learning output_ICT |
| Huang et al. (2020) | Natural science | Elementary students | 2 hours | Plant knowledge of learners cognitive load (mental load & effect) |
| Liu (2024) | Gamified mobile learning | Students from a technical college | No data | English proficiency |
| Lee and Lai (2024) | Gamified mobile collaborative learning approach | Fifth-grader | 4 weeks | Mathematics learning achievement intrinsic motivation extrinsic motivation tendency of cooperation performance |
| Lin et al. (2021) | Learning English | University students | 6 weeks | Learning performance & self-efficacy |
| Rashtchi and Porkar (2020) | Essay writing | Undergraduate students majoring in English translation | 14 weeks | Essay writing |
| Zhang and Hwang (2023) | Mathematics learning achievement | Junior high school students | 4 weeks | Mathematics learning achievement |
| Zou and Li(2015) | Story writing | Primary school students | No data | Chinese language test |

is most suited. The outcomes will have significant ramifications for enhancing teaching strategies and directing next research projects.

When the descriptive characteristics of the studies included in this meta-analysis are examined, the diversity and scope of research conducted in the field of MSCL are clearly revealed (**Table 2**).

When the thematic distribution of the studies included in the meta-analysis is examined, it is seen that these studies cover various fields such as mathematics, language learning (especially English), science, ICT, and writing skills. The sample groups ranged from primary school students to university students. This diversity demonstrates the applicability of MSCL at different educational levels and disciplines.

When the implementation periods of the studies are analyzed, it is seen that the periods vary from short time periods such as 2 hours to long periods such as 14 weeks. Some studies do not provide any information on this subject. This variability suggests that MSCL is potentially suitable for both short-term interventions and long-term applications.

The measurement tools and outcomes assessed by the studies included in the meta-analysis also varied. The studies examined different variables such as academic achievement, motivation (intrinsic and extrinsic), collaborative disposition, learning performance, self-efficacy and cognitive load. This diversity reflects a research effort to understand the multidimensional effects of MSCL on the learning process. The vast majority of studies reported positive effects of MSCL on the variables examined. For instance, a Lee and Lai (2024) gamified mobile cooperative learning strategy raised students' mathematical performance, motivation, and collaborative inclination. Comparably, Lin et al. (2020) found that the cooperative learning strategy helped students' English reading and listening abilities get better.

Ultimately, MSCL has been investigated with diverse groups of students and in several learning environments. While most studies have shown favorable findings, there are notable variations in terms of the length of implementation, measuring instruments and variables investigated. This implies that more thorough investigation of the elements influencing the efficacy of MSCL is necessary since they present significant chances for further studies.

**Table 3.** Robust Bayesian meta-analysis overall effect size

| | Model summary | | | | Model averaged estimates | | | |
|---|---|---|---|---|---|---|---|---|
| | Models | P (M) | P(M\|data) | Inclusion BF | Mean | Median | 95% CI lower | 95% CI upper |
| Effect size (μ) | 18/36 | 0.5 | 0.555 | 1.246 | 0.262 | 0.000 | –0.344 | 0.887 |
| Heterogeneity (τ) | 18/36 | 0.5 | 1.000 | $9.673 \times 10^{+7}$ | 0.556 | 0.493 | 0.305 | 1.027 |
| Publication bias | 32/36 | 0.5 | 0.824 | 4.666 | | | | |

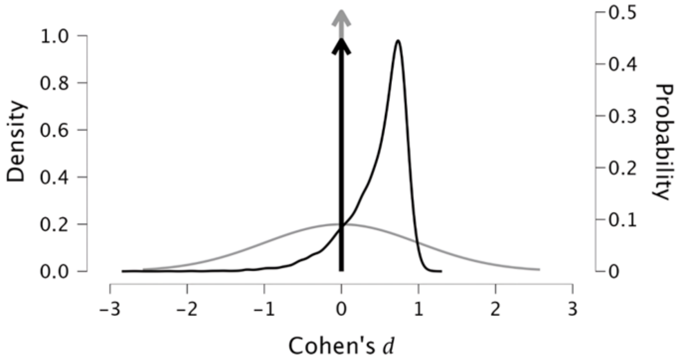


**Figure 2.** Distribution of effect size (generated by the authors)

According to **Table 3**, the inclusion BF for effect size (μ) is calculated as 1.246. This value provides weak evidence in favor of the presence of effect size. According to Jeffreys (1961) classification, BFs between 1 and 3 are considered as "anecdotal evidence". In this context, it can be said that more data is needed to reach a definite conclusion about the impact of MSCL.

The BF for the heterogeneity (τ) parameter is quite high ($9.673 \times 10^7$). This provides very strong evidence of a significant level of heterogeneity across studies. The presence of heterogeneity suggests that the effect sizes of the included studies differ significantly and that these differences are very unlikely to be due to random errors. The BF of inclusion for publication bias was found to be 4.666. According to Jeffreys classification, this value falls into the category of "moderate evidence". This provides an important indication of the presence of publication bias and is a factor that should be considered when interpreting meta-analysis results.

In terms of model selection, the difference between the posterior model probability for effect size (P [M|data] = 0.555) and the prior model probability (P [M] = 0.5) is small. This suggests that the fitting between the data and the model is reasonable. Ultimately, although this effect is not definitive, there is limited but favorable evidence for MSCL. High degrees of variability among research imply that the effect magnitude differs greatly between them. Publication bias exists in modest degree, which advises caution in result interpretation. These results emphasize the need for more study on the efficiency of mobile-supported cooperative learning and future studies should look for the causes of heterogeneity and reduce publication bias.

**Figure 2** shows the density distribution of the Cohen's (1988) d effect. There are values close to zero in the middle of the curve, which may indicate that the effect is generally zero or null. When publication bias and heterogeneity are considered, effects are concentrated around zero and large effects are less common.

The forest plot in **Figure 3** shows a great range in impact size between studies. While the lowest effect size was reported in Sung et al. (2016) (d = 0.10, 95% CI [0.46, 0.67]), Rashtchi and Porkar (2020) (d = 2.14, 95% CI [1.34, 3.14]) stated had the biggest effect size. This diversity implies that contextual elements can greatly affect the efficacy of MSCL. Much research had confidence intervals (CIs) that did not include 0 when the CIs were examined, therefore suggesting that these studies produced statistically significant results. Nonetheless, other studies (e.g., Liu, 2024; Rashtchi & Porkar, 2020; Sung et al., 2016) have CIs of zero, meaning that the statistical relevance of these investigations is more dubious.

The model-averaged effect size was calculated as 0.26 (95% CI [–0.34, 0.89]). This value indicates a small effect size according to Cohen (1988) classification. However, the fact that the CI is wide and includes zero indicates that the overall effect is not definite and the statistical significance is borderline. Overall, this forest plot provides a heterogeneous picture of the effectiveness of MSCL. Although the total impact was modest

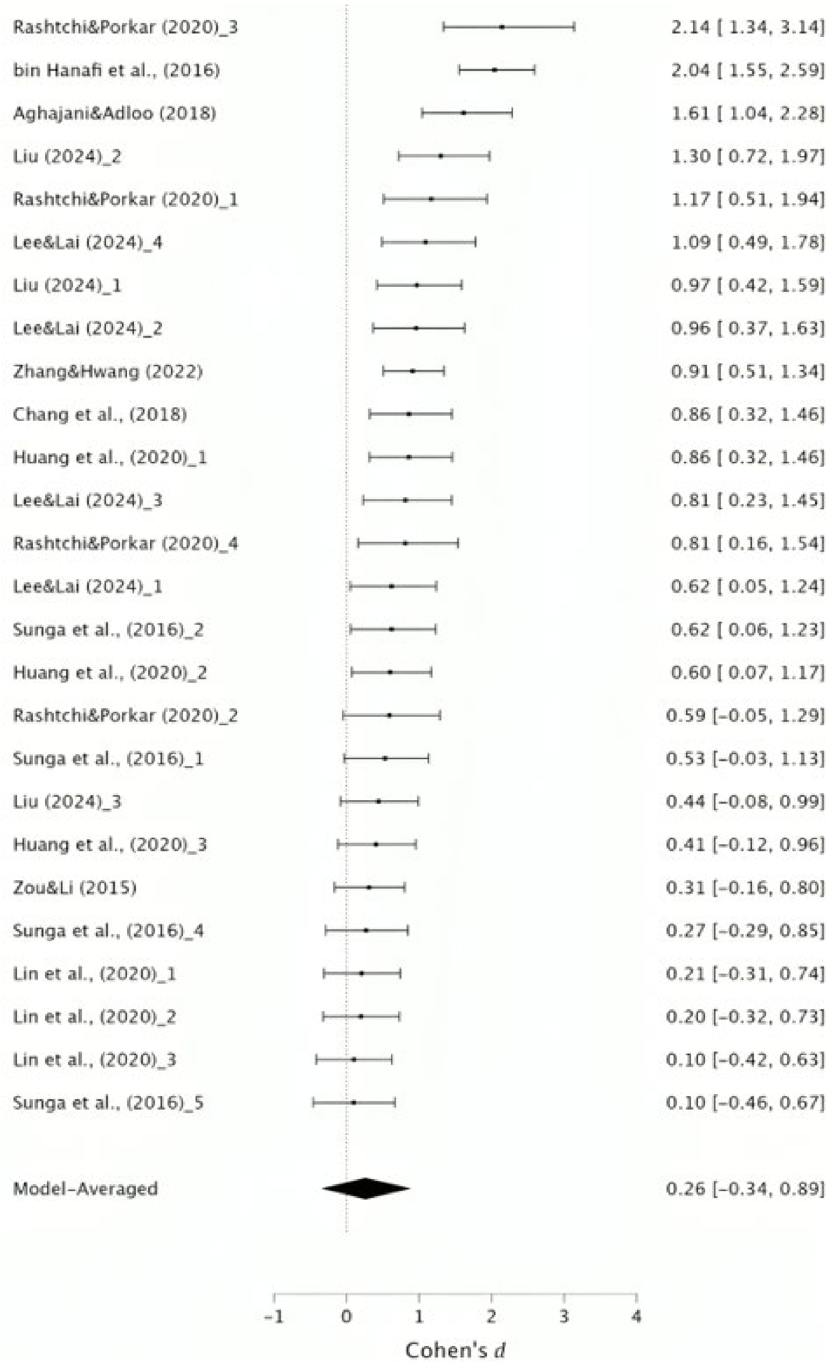


**Figure 3.** Forest plot (generated by the authors)

and uncertain, in some particular situations notable positive results were seen. This heterogeneity emphasizes the need for future study to investigate under which circumstances and for which groups of students MSCL is most successful. Moreover, moderate studies should be carried out to prove the causes of this variability more closely.

On Cohen's (1988) d scale, **Figure 4** displays on the gray line the posterior probability density function and on the black line the cumulative distribution function of the τ parameter. A gauge of meta-analysis heterogeneity, the parameter τ shows the square root of the variance across studies. The mode of the posterior distribution is around 0.5, indicating a moderate level of heterogeneity. This value indicates significant differences between studies. The posterior distribution is concentrated between 0 and about 2 but shows a long tail towards higher values. This indicates that there is uncertainty about the exact value of heterogeneity, but that a low to moderate level of heterogeneity is more likely. The fact that the distribution

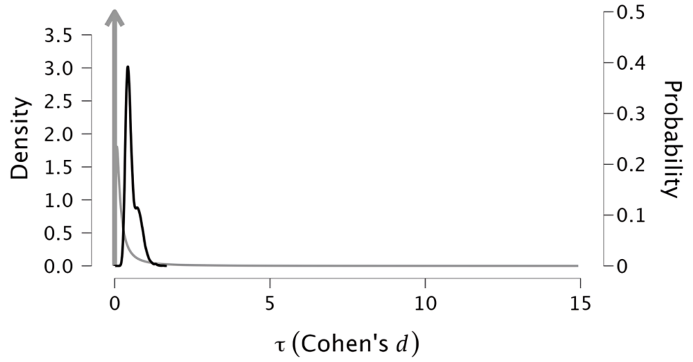


**Figure 4.** Cohen's density graph (generated by the authors)

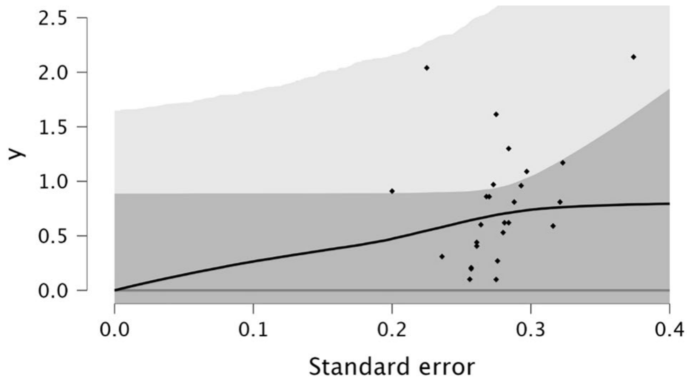


**Figure 5.** PET-PEESE graph (generated by the authors)

**Table 4.** Model averaged PET-PEESE estimates

| | Mean | Median | 95% CI | |
|---|---|---|---|---|
| | | | Lower bound | Upper bound |
| PET | 0.37 | 0.00 | 0.00 | 3.166 |
| PEESE | 2.322 | 0.00 | 0.00 | 11.669 |

is not very close to zero suggests that homogeneity across studies (τ = 0) has a rather low probability. The distribution has a long tail, indicating that high values of heterogeneity are also possible, but less likely. This heterogeneity distribution confirms that the effectiveness of MSCL varies significantly across studies. This indicates that the effect may vary according to contextual factors (e.g., student characteristics, implementation time, subject area).

**Figure 5** shows the relationship between standard error (x-axis) and effect size (y-axis). The black dotted line represents the estimate of the PET-PEESE model. The gray shaded areas represent CIs. The line shows an almost linear increase at low standard errors and a plateau at high standard errors. This indicates that small studies (with high standard errors) may tend to report larger effect sizes. The points show a wide dispersion, especially of a high standard errors. This supports the fact that there is considerable heterogeneity across studies. The graph shows a slight asymmetry to the right, which may indicate a potential publication bias.

PET estimates the true effect size in the absence of bias (as shown in **Table 4**). Although the mean value is positive, the CI contains zero, indicating that statistical significance is borderline. PEESE estimates the adjusted effect size in the presence of publication bias. Although the mean value is rather large, the wide CI and zero median point to the uncertainty of this estimate as well.

Though the degree and accuracy of this effect are unknown, there is some proof of publishing bias. Particularly PEESE, adjusted effect size estimates exhibit rather large confidence ranges, suggesting a low estimate precision. The significant discrepancy between the PET and PEESE estimations suggests that publication bias may have a significant influence, however this effect is not certain.

**Table 5.** Comparison of learning out subgroup results

| Group | Inclusion BF | Effect size (μ) | 95% CI | Heterogeneity (τ) | 95% CI |
|---|---|---|---|---|---|
| All studies | 1.246 | 0.262 | [−0.344, 0.887] | 0.556 | [0.305, 1.027] |
| Academic learning out | 1.644 | 0.349 | [−0.317, 1.007] | 0.603 | [0.324, 1.132] |
| Motivation | 3.318 | 0.529 | [−0.264, 1.202] | 0.136 | [0.000, 0.904] |
| Other skills | 1.330 | 0.171 | [−0.560, 0.683] | 0.114 | [0.000, 0.582] |

**Table 6.** Comparison of educational level subgroup results

| Group | Inclusion BF | Effect size (μ) | 95% CI | Heterogeneity (τ) | 95% CI |
|---|---|---|---|---|---|
| All studies | 1.246 | 0.262 | [−0.344, 0.887] | 0.556 | [0.305, 1.027] |
| Elementary | 1.190 | 0.170 | [−0.800, 0.811] | 0.039 | [0.000, 0.244] |
| High school | 3.715 | 0.374 | [0.000, 0.758] | 0.172 | [0.000, 0.696] |
| University | 1.940 | 0.435 | [−0.347, 1.201] | 0.718 | [0.382, 1.355] |

## Moderator Results

### *Learning out*

As shown in **Table 5**, comparatively to academic learning results (0.529 vs. 0.349), motivation has a more impact. Stronger proof of the existence of an impact on motivation comes from the BF of inclusion computed for motivation, which is also greater (3.318 vs. 1.649).

Motivation has a lower τ value (0.136 vs. 0.603), indicating better homogeneity and hence more consistent effect on motivation. The CIs for both groupings, however, contain zero, suggesting uncertainty about whether the effects are statistically significant.

Comparatively to the other talents, motivation has a larger BF (3.318 vs. 1.33) and a greater effect size (0. 529 vs. 0.171). This result implies that, among other abilities, MSCL has a more exact and greater impact on motivation. Regarding heterogeneity, both groupings have low τ values; yet, the CI of the motivated group is larger, so reflecting the variation of the outcomes.

Comparatively to other skills, academic learning outcomes had a larger effect size (0.349 vs. 0.171) and a somewhat higher BF (1.644 vs. 1.330). This implies that, compared to other abilities, the effect of MSCL on academic learning outcomes could be more significant. However, academic learning outcomes exhibit a higher heterogeneity (τ = 0.603 vs. 0.114), implying that the effect shows more variability across academic learning outcomes.

Motivation has a larger effect size (0.529 vs. 0.262) and a higher BF (3.318 vs. 1.246) compared to the overall outcomes. Academic learning outcomes have an effect size close to the overall results (0.349 vs. 0.262) and a slightly higher BF (1.644 vs. 1.246). Although the other skills have a lower effect size (0.171 vs. 0.262) compared to the overall results, the BF is slightly higher (1.33 vs. 1.246).

In conclusion, comparative analysis shows that the strongest and most consistent effect of MSCL is on motivation. The effect on academic learning outcomes is weaker than the effect on motivation, but stronger than on other skills; however, this effect exhibits a higher level of heterogeneity. The effect on other skills is the weakest, but this group shows the lowest heterogeneity. CIs for all subgroups and overall results include zero, indicating that caution should be exercised regarding the statistical significance of these effects. The results suggest that MSCL learning is particularly effective in increasing student motivation, but its effects on academic learning outcomes and other skills are more variable and less certain. Future research should examine in more depth the origins of these differences and under what conditions the most effective results can be achieved.

### *Educational level*

The results in **Table 6** suggest that, at the high school level, MSCL's impact seems to be more significant and consistent than at the elementary school level. While the evidence at the elementary level stays minimal, the BF acquired at the high school level offers a modest degree of proof. Furthermore, the found heterogeneity at the high school level points to additional variance in the effect. On the other hand, the influence is smaller but more constant at the elementary level. The higher impact size and BF seen at the university level than at the elementary school level imply that mobile-supported cooperative learning could be more successful there as well. However, heterogeneity is quite high at the university level, indicating that the effect is highly variable.

Although effect size observed at the university level is slightly higher than at the high school level, the BF is higher at the high school level. This provides greater evidence of the high school level influence. However, the variances at the university level are significantly higher than those at the high school level, suggesting more change in influence there. The effect magnitude at the university and the secondary school levels surpasses the general results. The high school level provides the best proof of the existence of the effect among others with the highest BF. Regarding homogeneity, the university level displayed the highest degree and the primary school level the lowest degree.

Ultimately, depending on educational level, the impact of mobile-supported cooperative learning exhibits notable variations. At the high school level, the effect size was moderate and the best proof of an existence of an effect came from here. Although the biggest effect size was noted at the university level, this effect was shown to be somewhat erratic. At the primary school level, the effect was the smallest and most consistent, and the evidence for the existence of an effect was weak. CIs for all subgroups and overall results included zero (except for high school), suggesting caution about the statistical significance of these effects. These results suggest that MSCL may be more effective, especially at the high school and university levels, but that this effect may vary depending on contextual factors. Future research should examine in more detail the reasons for these differences and the conditions under which the most effective results can be achieved.

## DISCUSSION

This meta-analysis aimed to find MSCL's potency. Results show that MSCL has an overall small but positive effect on learning results ($d = 0.26$, 95% CI [–0.34, 0.89]). This result emphasizes the need of moderation on the degree and consistency of the effect even if it supports the probable benefits of MSCL. The modest positive impact size implies that MSCL could help to enhance learning mechanisms. This result conforms to the meta-analysis by Sung et al. (2017). They also discovered that using mobile devices in group projects had general favorable results in collaborative learning. Nonetheless, the borderline statistical relevance of the effect magnitude in our study implies that contextual elements could determine the efficacy of MSCL.

Our results showed a considerable degree of study heterogeneity ($\tau = 0.556$, 95% CI [0.305, 1.027]). This result implies that the effectiveness of MSCL can change dramatically depending on the situation. As Fu and Hwang (2018) point out, this variation could result from the variety of MSCL techniques. Different collaborative learning approaches, degrees of technological integration, and length of deployment could all influence the outcomes, for instance.

A moderate level of publication bias was identified in our study (inclusion BF = 4.666). This findings implies that in MSCL research beneficial outcomes could often be over-reported. Although this shows the overall direction in the field, it also underlines the need to use caution in analyzing the outcomes. Positive outcomes usually find publication in educational research, according to Fanelli (2012), which validates our conclusions. Our findings showed that MSCL had a strong and consistent effect, especially on motivation. This result is in line with Lee and Lai (2024), who also found that a gamified mobile collaborative learning approach increased student motivation. The moderate impact on academic learning outcomes is in line with the findings of Lin et al. (2021). The great variety in this field, however, implies that the influence of MSCL on academic performance could be more sensitive to contextual elements.

Particularly at the high school level, our studies revealed that MSCL had the most constant effect. Adolescents' inclination to technology use and their cognitive maturity required for cooperative learning could help to explain this result. Studies show that teenagers' cognitive and social development is much influenced by their technology consumption. Often referred to be "digital natives," teenagers seem to fit technology perfectly into their educational environments. This integration improves not just their individual learning but also their group projects, including cooperative learning in which technology supports project organization, task management, and group member communication enhancement (Benvenuti et al., 2023; Johnson & Johnson, 2014). The huge effect size and great variety noted at the university level mirror both the possibilities and the difficulties in MSCL application in higher education. This result conforms to the methodical study of mobile learning in higher education published by Crompton and Burke (2018).

In conclusion, this meta-analysis shows that MSCL has the potential to improve learning processes, but that this effect is highly dependent on contextual factors. In particular, its positive effect on motivation and its consistent results at high school level suggest that MSCL can be used as an effective tool in education. However, high heterogeneity and publication bias highlight the need for caution in generalizing the results. When implementing MSCL, educators and policy makers should consider the potential benefits and limitations of this approach. Given that MSCL is particularly effective in increasing student motivation, it may be advisable to use this approach strategically to increase student engagement. However, given that the impact on academic achievement is more variable, it is important to supplement MSCL with other teaching approaches and tailor it to student needs.

## CONCLUSION

This meta-analysis systematically investigates the efficiency of MSCL. The results show that MSCL have moderate but positive effects on learning outcomes. Especially with relation to student motivation, this influence was demonstrated to be clearer and more constant. Furthermore, it was discovered that MSCL's efficacy changed with educational level; more consistent outcomes, particularly in the high school level, were obtained.

Nonetheless, the great variation shown between trials indicates that environmental elements significantly determine the efficacy of MSCL. This suggests that the success of MSCL implementation is influenced by various factors such as student characteristics, technological infrastructure, teacher competencies and implementation strategies.

While this meta-analysis highlights the value of MSCL as a potential improvement tool in education, it also highlights the need for careful planning and implementation to increase the effectiveness of this approach and achieve more consistent results.

### Recommendations

Educators should consider using MSCL as a strategic tool, especially to increase student motivation. Plans for interventions using MSCL should take age and degree of education of the pupils into account. Especially, it is advisable to give applications at the high school level first attention. Educational institutions should provide the necessary technology tools and enough assistance for teachers in order to utilize MSCL correctly. Future studies should pay more attention to the particular elements either favorably or negatively influencing MSCL's performance. Particularly one should consider the effects of several cooperative learning approaches, degrees of technology integration, and length of deployment.

### Limitations of the Study

The limited number of studies included in this meta-analysis (n = 11) limits the generalizability of the findings. The moderate publication bias detected in the study indicates that caution should be exercised in interpreting the results. The high level of heterogeneity makes it difficult to fully understand the factors affecting the effectiveness of MSCL. This meta-analysis includes only quantitative data. The exclusion of results from qualitative studies limits a deeper understanding of the effectiveness of MSCL. Most of the studies examined short-term interventions. Data on the long-term effects of MSCL are limited. Despite these limitations, this meta-analysis provides important insights into the effectiveness of MSCL and guides future research and implementation efforts. To realize the full potential of MSCL, more research is needed to better understand the effects of this approach in different contexts.

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