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Effectiveness of Math Universe on Students' Combinatorics Understanding for Mathematics Olympiad Preparation

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Math Universe, Combinatorics, Mathematics Olympiad, Self-Directed Learning

Abstract

Mathematics olympiads require higher-order thinking skills, logical reasoning, and mastery of non-routine material, one of which is combinatorics, a topic often considered difficult by students. Limitations in face-to-face coaching have encouraged the need for structured independent learning media that align with the characteristics of olympiad problems. This study aims to examine the effectiveness of the Math Universe application on students' conceptual understanding of combinatorics in mathematics olympiads. The study employed a quantitative approach with a one-group pre-test–post-test design. The research subjects consisted of 40 students who were members of the Komunitas Pecinta Matematika (KPM). The research instrument was an olympiad-level combinatorics test administered before and after the use of the Math Universe application. Data were analyzed using a paired sample t-test. The results showed a significant difference in learning outcomes before and after the use of the Math Universe application. These findings indicate that Math Universe is effective in improving combinatorics learning outcomes through independent learning based on self-directed learning and mobile learning. This application has the potential to serve as a supporting medium for mathematics olympiad training, particularly for materials with a high level of complexity.

Introduction

The mathematics olympiad is an academic competition that demands higher-order thinking skills, deep mathematical reasoning, and creativity in solving non-routine problems (Muzaini et al., 2021). The characteristics of olympiad problems—which are open-ended, challenging, and not always solvable through routine procedures—make this competition significantly different from mathematics learning in regular classroom settings (Tohir, 2019a). Consequently, students' success in mathematics olympiads is not determined solely by mastery of mathematical content, but also by reasoning ability, cognitive flexibility, and independence in learning and practicing problems (Tantrawan et al., 2025).

In practice, mathematics olympiad coaching in schools still largely depends on the role of mathematics teachers as mentors (Tohir, 2019b). Teachers often face limitations in terms of time allocation, learning resources, and variation of olympiad problems, resulting in mentoring processes that are not yet fully optimal (Wahyu Iskandar et al., 2023). Research by (Renta et al., 2024) shows that peer tutoring can serve as an alternative to overcome these limitations; however, this approach is considered inflexible and constrained by space and time. These conditions encourage students to engage in self-directed learning as a primary strategy for olympiad preparation. Nevertheless, self-directed learning also presents challenges, particularly when students do not have access to structured, interactive learning media that align with the characteristics of olympiad-level problems (Suhendar et al., 2020).

Self-Directed Learning (SDL) refers to a learning process in which learners take the initiative to diagnose learning needs, formulate learning goals, identify learning resources, and evaluate learning outcomes independently (Etemi et al., 2024; Xu et al., 2024). SDL is also defined as the improvement of achievement, skills, and knowledge initiated by learners themselves through self-planned learning, driven by awareness of learning needs to achieve specific learning objectives (Hanik, 2020). In the context of mathematics olympiads, SDL becomes particularly important because olympiad materials are extensive and not fully covered within the regular school curriculum (Ardhuha et al., 2023). The integration of technology plays a crucial role in facilitating SDL, functioning not only as a source of information but also as a facilitator that supports the development of self-regulation, learner autonomy, and responsibility for learning (Mohammadi, 2024).

One form of technology that effectively supports self-directed learning is mobile learning. Mobile learning enables students to access learning materials anytime and anywhere through digital and electronic devices (Faqih, 2021; Samsinar, 2021). Several studies have reported that mobile learning contributes positively to students' learning outcomes, particularly in independent learning contexts (Elmi et al., 2023; Kurniasih et al., 2020). In mathematics education, mobile learning provides flexibility and opportunities for repeated practice, which are essential for mastering complex and non-routine materials such as those encountered in mathematics Olympiads (Tang et al., 2023; Wang et al., 2021).

Along with the rapid development of digital technology, various online learning applications such as Ruangguru and Zenius have been widely utilized to support students' learning processes (Rahmadani & Setiawati, 2019; Yanur et al., 2024). However, these

applications are generally oriented toward regular curriculum learning and do not specifically address the needs of mathematics olympiad students, who require deeper conceptual understanding and exposure to high-level problem-solving tasks. In response to this gap, a learning application called Math Universe was developed by (Utami et al., 2024) to support senior high school students' self-directed learning in preparation for mathematics olympiads. Developed using the Plomp model, Math Universe integrates learning videos, modules, a question bank, a ranking system, and interactive features designed to support independent practice and evaluation.

Previous studies on Math Universe have primarily focused on its development and validation, particularly in terms of interface design, practicality, and feasibility of use. The findings indicate that Math Universe is suitable as a self-directed learning medium and aligns well with the characteristics of mathematics olympiad problems (Utami et al., 2024). However, despite evidence of its feasibility, these studies have not empirically examined the effectiveness of Math Universe in improving students' learning outcomes. In other words, research investigating whether the use of Math Universe leads to measurable improvements in students' conceptual understanding—especially in specific olympiad topics—remains limited. This lack of empirical evidence represents a clear research gap that warrants further investigation.

One of the most challenging topics in mathematics olympiads is combinatorics. Based on preliminary interviews with members of the Komunitas Pecinta Matematika (KPM) at SMA Negeri 2 Balikpapan, combinatorics is perceived as one of the most difficult materials by students. This difficulty arises because combinatorics requires not only computational skills but also the ability to understand problem structures, systematically organize possible cases, and determine appropriate solution strategies. Combinatorics requires logical and systematic thinking to determine possible outcomes based on given rules (Wulandari & Pujiastuti, 2020) and involves not only computational skills but also the ability to identify problem structures and appropriate solution strategies (Pratiwi et al., 2023).Previous studies have shown that students' errors in solving combinatorics problems are caused by various factors, including difficulties in identifying the problem (Triyani & Pujiastuti, 2020), incorrect use of formulas (Matitaputty et al., 2023), and and procedural errors during problem solving (Tamariska et al., 2025). This condition indicates that learning difficulties in combinatorics are a common issue encountered in mathematics education (Annisa Amalia & Pujiastuti, 2020).

Furthermore, learning difficulties in combinatorics are often associated with misconceptions in distinguishing between permutations and combinations, misunderstandings of underlying concepts, and errors in applying relevant formulas (Hafidz & Masriyah, 2020; Prayitno et al., 2024; Putri et al., 2022). Differences in learning styles also contribute to these difficulties (Angrenani et al., 2025). These challenges are exacerbated in the context of mathematics olympiads due to the limited coverage of combinatorics in the senior high school curriculum, which typically focuses only on basic topics such as the multiplication principle, permutations, combinations, and the binomial theorem, usually taught in Grade XII. In contrast,

olympiad participants often come from Grade X and XI, resulting in insufficient conceptual readiness when entering olympiad training (Herizal, 2021).

Although various studies have explored students' learning difficulties in combinatorics and the development of mobile-based learning media, research that specifically examines the effectiveness of a self-directed, mobile learning application tailored for mathematics olympiad preparation—particularly in improving students' conceptual understanding of combinatorics—is still scarce. Therefore, addressing this research gap, this study aims to examine the effectiveness of using the Math Universe application on the learning outcomes of mathematics olympiad students in combinatorics using a pre-test and post-test design. The study was conducted on the same subjects as the previous Math Universe application development research, namely 40 members of the Komunitas Pecinta Matematika (KPM), with differences in learning outcomes before and after the use of the application analyzed using a paired sample t-test.

Method

Research Design

This study employed a quantitative research approach aimed at examining the effectiveness of the Math Universe application on the learning outcomes of mathematics olympiad students in combinatorics. According to Sugiyono, quantitative research is an approach applied to a particular population or sample by utilizing research instruments and numerical or statistical data analysis techniques to test the validity of formulated hypotheses (Syahroni, 2022).

The research design used in this study was a one-group pre-test–post-test design. This design involves administering an initial measurement (pre-test) to a single group of research subjects, followed by the provision of a treatment or intervention, and concluding with a final measurement (post-test) to examine changes that occur as a result of the intervention (William & Hita, 2019). Based on this design, the hypotheses proposed in this study are as follows:

H_0: There is no significant difference in students' conceptual understanding of combinatorics after using the Math Universe application.

H_1: There is a significant difference in students' conceptual understanding of combinatorics after using the Math Universe application.

The research design procedure is illustrated as follows:

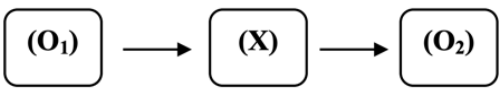

Figure 1. Research Flow of the One-Group Pre-Test–Post-Test Design

Description

O1 : Pre-test (administered before the treatment)

X : Treatment in the form of learning using the Math Universe application

O2 : Post-test (administered after the treatment)

Research Data

The population of this study consisted of senior high school students participating in mathematics olympiad coaching or extracurricular activities. The research sample comprised 40 students who were members of the Komunitas Pecinta Matematika (KPM) at SMA Negeri 2 Balikpapan.

The sample used in this study was the same as that employed in the previous Math Universe application development research conducted by (Utami et al., 2024), The use of the same sample ensured continuity between the application development phase and the effectiveness testing phase, allowing the impact of the Math Universe application to be examined more consistently. The research data consisted of students' pre-test and post-test scores on combinatorics material at the senior high school mathematics olympiad level.

Data Collection Technique

The data collection technique used in this study was a test method in the form of pre-test and post-test. The research instrument consisted of five combinatorics questions at the senior high school mathematics olympiad level, developed from problems used in the Kompetisi Sains Nasional Tingkat Kabupaten/Kota (KSN-K) and the Olimpiade Sains Nasional (OSN). The same set of questions was administered for both the pre-test and the post-test to ensure that differences in learning outcomes reflected the effect of the Math Universe application rather than variations in test difficulty.

The research procedure began with the administration of a pre-test, which students were required to complete within one hour to assess their initial ability in combinatorics. This was followed by a one-week period of self-directed learning using the Math Universe application, during which students utilized learning video features and combinatorics modules provided in the application. The procedure concluded with the administration of a post-test, conducted within the same duration as the pre-test, to measure students' abilities after using the application.

Data Validation Technique

Data validation in this study was conducted through statistical analysis of pre-test and post-test scores using a paired sample t-test with the assistance of SPSS. This test was employed to determine whether there was a significant difference in students' learning outcomes before and after the use of the Math Universe application.

The paired sample t-test was selected because the data were obtained from the same group of students measured at two different times. Based on the proposed hypotheses, the results of the analysis were used as the basis for hypothesis testing and for achieving the research objective, namely to examine the effectiveness of the Math Universe application in improving mathematics olympiad students' understanding of combinatorics.

Results and Discussion

Analysis of Paired Sample t-Test Results

Based on the results of the analysis using a paired sample t-test conducted with the assistance of SPSS, a clear depiction of changes in students' learning outcomes before and after using the Math Universe application on combinatorics material was obtained. This analysis was carried out to compare students' learning achievements in the initial condition prior to instruction with their achievements after engaging in self-directed learning using the Math Universe application.

The results indicate a significant difference between students' pre-test and post-test scores. At the initial stage, the pre-test results reflected students' limited understanding in solving olympiad-level combinatorics problems, as evidenced by low levels of conceptual mastery and accuracy in selecting appropriate problem-solving strategies. After students participated in learning activities using the Math Universe application, the post-test results demonstrated an improvement in students' understanding of combinatorics. This improvement indicates that students experienced progress in conceptual comprehension, enhanced their ability to recognize problem structures, and applied more appropriate strategies in solving combinatorics problems.

Pre-test and Post-test Statistics

Based on the statistical results obtained from the t-test analysis, an initial overview of students' abilities before and after receiving the treatment in the form of self-directed learning using the Math Universe application was obtained. The statistical data are presented in Table 1.

Table 1. Paired Sample Statistics

		Mean	N	Std. Deviation
Pair 1	Before treatment	33.5000	40	14.59715
	After treatment	77.0000	40	15.39231

The value of N = 40 indicates that the research sample consisted of 40 students who were members of the Komunitas Pecinta Matematika (KPM). The pre-test mean score of 33.50 indicates that students' initial ability to solve olympiad-level combinatorics problems was relatively low. After the implementation of the Math Universe application, the mean post-test score increased to 77.00, indicating a substantial improvement in students' understanding of combinatorics.

The standard deviation values of 14.60 for the pre-test and 15.39 for the post-test suggest that the distribution of students' scores in both conditions was relatively consistent, despite the overall improvement in learning outcomes. The mean difference of 43.50 points indicates a considerable increase in students' conceptual understanding following the treatment.

Correlation Between Pre-Test and Post-Test Scores

The relationship between pre-test and post-test scores was analyzed using a paired samples correlation test, as presented in Table 2.

Table 2. Paired Samples Correlation

				Significance
		N	**Correlation**	**Two sided *p***
Pair 1	Before treatment & After treatment	40	.367	.020

The correlation coefficient of 0.367 indicates a positive relationship with a moderate level of correlation between pre-test and post-test scores. This finding suggests that students who demonstrated higher initial ability tended to achieve higher post-test scores, although improvement was still observed in nearly all students.

The significance value of 0.020, which is lower than the significance level of 0.05, indicates that the relationship is statistically significant. Thus, students' initial ability has a meaningful association with their final performance; however, it does not negate the effect of the treatment provided.

Results of the Paired Sample t-Test

Hypothesis testing was conducted using a paired sample t-test to determine whether there was a significant difference between students' pre-test and post-test scores. The results of the test are presented in Table 3.

Table 3. Paired Sample t-Test

		Mean Difference	**t**	**df**	**Two sided p**
Pair 1	Before treatment & After treatment	-43.50	-16.300	39	<.001

The mean difference value of –43.50 indicates that the average post-test score was higher than the average pre-test score. The negative sign appears because the difference was calculated by subtracting the post-test score from the pre-test score. The obtained t-value of –16.300 with 39 degrees of freedom (df) indicates that the difference between the mean pre-test and post-test scores is very large relative to the existing data variability. The degrees of freedom, derived from the research sample size of 40 students, indicate that the statistical test was based on sufficient information to draw reliable conclusions.

The t-value, which is far from zero, suggests that the improvement in students' learning outcomes was not due to random fluctuations, but rather represents a genuine effect of the treatment provided. This finding is further supported by the very small two-tailed significance value, leading to the conclusion that the use of the Math Universe application had a significant effect on improving students' understanding of combinatorics. The two-tailed significance

value ($p < 0.001$) is far below the significance level of 0.05; therefore, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted.

Based on these results, it can be concluded that there is a significant difference in learning outcomes before and after the use of the Math Universe application. The observed increase in scores indicates that this application is effective in supporting students' understanding of combinatorics concepts and enhancing their ability to solve mathematics olympiad–level problems.

The Effectiveness of Math Universe in Supporting Olympiad-Level Combinatorics Learning

The improvement in students' combinatorics learning outcomes observed in this study indicates that the Math Universe application functions not only as a practice tool but also as a learning environment capable of facilitating higher-order mathematical thinking processes. The increase in the mean post-test score to 77, compared to the pre-test mean score of 33, demonstrates that Math Universe effectively supports the enhancement of students' conceptual understanding during the learning process. These findings can be explained through the framework of self-directed learning, which positions students as the primary agents in controlling their own learning processes. Malcolm Knowles emphasizes that self-directed learning is effective when learners are aware of their learning needs, which, in the context of mathematics olympiads, arise from the demands of solving non-routine and high-level problems (Mahlaba, 2020).

Math Universe is designed with a structured learning system that allows students to access materials, instructional videos, and practice problems in a gradual and systematic manner. This structure aligns with Zimmerman's view that self-regulation in learning encompasses the phases of planning, performance, and reflection (Boor & Cornelisse, 2021). In this study, Math Universe served as a medium that expanded students' learning space and time, thereby providing greater opportunities for students to explore various types of combinatorics problems that require advanced reasoning skills. Through this application, students were able to plan the content they studied, test their understanding through the question bank, and independently evaluate their learning achievements. This process contributed to the strengthening of conceptual understanding, which constitutes a crucial foundation for solving combinatorics problems at the olympiad level.

Mobile Learning as a Medium for Strengthening Combinatorial Reasoning

The effectiveness of the Math Universe application is closely related to the characteristics of mobile learning, which offer flexibility in terms of learning space and time. Crompton states that mobile learning enables personalized and contextual learning experiences, allowing students to adapt their learning processes to their individual needs (Tang et al., 2023). In combinatorics learning, this flexibility is particularly crucial, as problem solving often requires the exploration of multiple possibilities and solution strategies.

Research conducted by (Kurniasih et al., 2020) demonstrates that the implementation of mobile-based learning in instructional processes is effective in delivering mathematics

content. Moreover, this approach is capable of fostering students' independence in enhancing their understanding of the subject matter. Smart mobile devices need to be optimally utilized in the development of mobile learning as a supportive medium for mathematics education. Through the use of such technology, learning processes can be designed to be more flexible, interactive, and easily accessible, thereby improving conceptual understanding and promoting learners' autonomy (Wang et al., 2021).

In the context of mathematics olympiads, research by (Apriyono et al., 2025) provides evidence that mobile-based learning is effective in improving olympiad students' understanding. The results of the t-test analysis further confirm that the mobile-based Math Universe application significantly enhances students' conceptual understanding, leading to higher test scores. As Math Universe can be accessed via mobile devices, it enables practical learning that is not constrained by time and location. In addition, it provides students with opportunities for repeated practice using a wide variety of problems. This allows students not only to memorize formulas, but also to develop the ability to organize cases and recognize patterns, which constitute the core of combinatorial reasoning.

The Role of Math Universe in Enhancing Conceptual Understanding of Combinatorics

The findings of this study also contribute to a deeper understanding of learning difficulties in combinatorics. Numerous studies indicate that students' difficulties in combinatorics are not solely related to computational aspects (Dewi et al., 2024; Pratiwi et al., 2023), but are more strongly associated with an inability to understand underlying concepts (Nurmitasari et al., 2020) and to systematically organize possible cases (Alfania & Sulistyanigtyas, 2025). Students often experience obstacles in interpreting problem situations, determining relevant sample spaces, and selecting appropriate solution strategies that align with the given conditions (Prayitno et al., 2024). These limitations tend to lead students to apply procedures mechanically without understanding the logical foundations of the solutions produced, thereby increasing the likelihood of both conceptual and procedural errors (Herizal, 2021).

The Math Universe application is designed to address these challenges by presenting learning materials that emphasize understanding the problem context before applying solution techniques. The practice problems provided are not merely oriented toward obtaining final answers, but guide students to identify essential information, map possible cases, and construct solution strategies in a gradual and systematic manner. This approach supports the development of more structured and reflective combinatorial thinking, enabling students to move beyond rote memorization of formulas and instead reason through solutions based on the characteristics of the problems encountered.

This instructional approach aligns with the perspective of George Polya on the importance of understanding the problem as the initial step in mathematical problem solving (Tambunan, 2019). By providing exercises that emphasize situation analysis and strategic reasoning, Math Universe helps students build more systematic cognitive schemas. This

explains why the application is effective in improving learning outcomes in a topic that has long been regarded as challenging by mathematics olympiad participants.

Theoretical and Practical Implications for Mathematics Olympiad Training

Theoretically, the findings of this study reinforce the relevance of self-directed learning and mobile learning theories in the context of advanced mathematics education. This study demonstrates that the integration of these two approaches is not only suitable for regular classroom learning but also effective for mathematics olympiad training, which requires a high degree of learner autonomy and depth of mathematical thinking.

Practically, the results of this study indicate that the Math Universe application can serve as a viable solution to the limitations of face-to-face olympiad coaching frequently encountered by schools. The application has the potential to function as a supplementary medium for olympiad training, particularly in combinatorics topics that demand intensive practice and strong conceptual understanding. Accordingly, Math Universe can be positioned as part of a sustainable and adaptive mathematics olympiad training strategy that aligns with ongoing technological advancements.

Conclusion

Based on the results and discussion of this study, it can be concluded that the use of the Math Universe application is effective in improving mathematics olympiad students' understanding of combinatorics. The application supports students' self-directed learning through the provision of well-structured learning materials, practice problems aligned with the characteristics of olympiad tasks, and flexible access to learning resources. The integration of self-directed learning and mobile learning approaches within Math Universe plays a significant role in helping students develop stronger conceptual understanding and improved combinatorial reasoning skills. Therefore, Math Universe can be considered a promising alternative learning medium for mathematics olympiad training, particularly for topics with high levels of complexity such as combinatorics.

Based on the findings of this study, several recommendations can be proposed for future research. Further studies are encouraged to employ experimental designs involving control groups, allowing the effects of using the Math Universe application to be compared more comprehensively with conventional learning approaches. In addition, future research may expand the scope of mathematics olympiad topics, such as number theory or geometry, to examine the consistency of the application's effectiveness across different content areas. Subsequent studies are also recommended to investigate aspects beyond learning outcomes, including mathematical reasoning ability, learning autonomy, and students' learning motivation, in order to obtain a more comprehensive understanding of the impact of Math Universe on mathematics olympiad learning.

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