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A website-based application integrating HOTS and functional thinking to enhance mathematical generalization ability

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ABSTRACT

Mathematical generalization, one of the essences of algebraic reasoning, allows students to perceive patterns and general rules. This study investigates the effect of a web-based application that integrates Higher-Order Thinking Skills (HOTS) and functional thinking on students' mathematical generalization abilities. Using an explanatory sequential mixed-methods design, the study involved 128 eighth-grade students from two public junior high schools in East Java, Indonesia. The students included 64 students from SMP Negeri 1 Trowulan and 64 students from SMP Negeri 6 Kediri. The learning process implemented in the experimental class used a website-based application, whereas the control class used student worksheets. The quantitative results revealed that students who engaged with the web-based application attained higher post-test scores in mathematical generalization ability relative to their peers assigned to the control class. Students also showed a positive response to the website-based application. Qualitative interviews revealed flexibility in learning the material and the strategies used by students in formulating the nth-term rule in algebraic form. The increase in students' mathematical generalization ability was more substantial among students in the experimental class than among those in the control class. The evidence presented in this study indicates that utilizing website-based learning to embed HOTS and functional thinking promotes mathematical generalization ability and meaningful mathematics learning.

Contribution/Originality: This study uses HOTS-based tasks that emphasize functional thinking in materials on mathematical patterns and delivers them to students through a web-based application. This feature sets our study apart from previous research. By integrating these tasks into the application, we aim to support and strengthen students' mathematical generalization skills.

1. INTRODUCTION

The ability to generalize is a critical component of learning mathematics (Chua & Hoyles, 2014), as it carries the cognition of a vast array of mathematical ideas (Callejo & Zapatera, 2017; Karabulut & Özmen, 2018). Moreover, curriculum standards emphasize the substance of generalization within mathematics education research (Tillema & Gatza, 2017). Generalization can be defined as the inquiry into recognized resemblances in relationships or attributes under specific conditions to embrace wider circumstances (Öz & Çiftci, 2024). Ellis further argues that generalization plays an important role in the construction of new knowledge and represents a fundamental aspect of mathematical

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activity (Jackson & Stenger, 2024). This process involves recognizing commonalities across different cases, engaging in extended reasoning, and drawing broader conclusions from particular instances (Jackson & Stenger, 2024). Thus, mathematical generalization is a thought process for studying patterns, determining relationships, and developing specific cases into more general rules. Thus, students can contribute new knowledge and expand their understanding of mathematical concepts.

More sophisticated and in-depth generalizations can be developed through the study of patterns (Mata-Pereira & da Ponte, 2017). Consequently, assessment tasks designed to evaluate generalization ability frequently incorporate numerical and geometric patterns (Joanna, 2017; Mulenga & Marbán, 2020). In this regard, students' capacity for mathematical generalization can be effectively assessed through their performance on pattern-based problems. Mathematical generalization is closely associated with functional thinking, as it represents a central component of this type of reasoning and is often developed through students' exploratory processes (Kieran, Pang, Schifter, & Ng, 2016). Functional thinking focuses on developing students' capacity to derive general relationships between quantities, represent them, and reason with those representations to predict functional behavior (Krüger, 2019; Stephens et al., 2017). Thus, mathematical generalization is inherently connected to functional thinking, as both involve recognizing and representing relationships between quantities, enabling students to reason about patterns and predict functional behavior through exploratory mathematical processes. Pattern-based activities may therefore enhance both generalization and functional reasoning by helping students examine and generalize relationships among changing quantities.

Based on previous research findings, it was shown that out of 50 eighth-grade junior high school students, 26 were able to perform generalization from the given patterns (Suryowati, Nusantara, Irawan, & Sudirman, 2019). Furthermore, according to the 2019 TIMSS results, Indonesian students displayed a low degree of proficiency in mathematical generalization (Ambussaidi & Yang, 2019). Therefore, enhancing junior high school students' generalization ability requires innovation in learning media as a source of instruction. Such media should be technology-based, as contemporary junior high school students belong to Generation Z, who have grown up as digital natives with early access to technology.

A web-based application can serve as a platform for delivering instructional media. In the present study, the learning medium is designed to be interactive, enabling students to develop higher-order thinking skills (HOTS) through cognitive activities such as analyzing (examining relationships), evaluating (assessing outcomes), and creating (generating new ideas), and it can be accessed via mobile phones. The primary novelty of the present study is the integration of Higher-Order Thinking Skills (HOTS) and functional thinking within a web-based application. The application incorporates various functional thinking–based activities, including identifying patterns recursively, observing changes in values between two quantities, and generalizing these relationships into algebraic forms. This application is grounded in Higher-Order Thinking Skills (HOTS), given that international assessments, including the Trends in International Mathematics and Science Study (TIMSS), continue to indicate relatively low levels of higher-order thinking among Indonesian students, which places Indonesia at a less satisfactory level (Hadi & Novaliyosi, 2019; Mejía-Rodríguez, Luyten, & Meelissen, 2021). In addition, it is based on functional thinking, as generalization constitutes an essential component of functional thinking (Kieran et al., 2016). The following research questions formed the basis of this study.

1. How do students in the experimental class and the control class differ in terms of their mathematical generalization ability?
2. How do students respond to the implementation of a website-based application that integrates Higher-Order Thinking Skills (HOTS) and functional thinking?
3. To what extent does the use of a website-based application that integrates Higher-Order Thinking Skills (HOTS) and functional thinking improve students' ability to generalize mathematically?

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2. LITERATURE REVIEW

2.1. Mathematical Generalization

Generalization approaches enable students to integrate their existing knowledge with new concepts, thereby narrowing the gap between previous understanding and new learning (Stacey, 1989). Therefore, generalization is considered an essential aspect of mathematical performance and a core aspect of mathematics teaching at every educational stage (Ellis, Tillema, Lockwood, & Moore, 2017). Generalization is an essential component of mathematics for identifying a general formula, whereby students extend a particular pattern into a general formula (Sosa Moguel, Aparicio Landa, & Cabañas-Sánchez, 2019). The generalization of number patterns is not only the ability to determine the similarities among sequential elements in a pattern but also the ability to understand the relationships among the elements and the observed rules, represent these relationships, and express them using symbols (general formulas). In fact, students have difficulty with mathematical generalization because they still struggle to recognize patterns, understand the relationships among elements, and represent them using appropriate symbols. The importance of developing students' generalization skills related to number patterns and picture patterns (object configurations) has been emphasized in previous studies (Anderson, Zhang, Borst, & Walsh, 2016; Pittig, Treanor, LeBeau, & Craske, 2018). Based on the findings of existing research, generalization is a multidimensional process, involving not just an understanding of regularity but also the expression, symbolization, and manipulation of general relationships. The importance of generalization and student involvement in pattern-based assignments has been extensively emphasized in previous studies and the existing literature, but this work has been limited to explicit learning that facilitates the transition from perceptual pattern recognition to formal symbolic generalization. This gap shows the need for learning that enables students to actively explore patterns, reveal emerging relationships, and gradually develop general rules (general formulas). This type of learning is well suited to investigating the potential of technology-based learning environments to assist students in the generalization process. In addition, it enhances deep and sophisticated mathematical reasoning.

Understanding patterns is an important skill in generalization. This is because they reveal the relationships and rules that underlie mathematical data. Thus, patterns are the basis for forming complex and profound generalizations (Mata-Pereira & da Ponte, 2017). Therefore, it can be said that understanding patterns is the first step in broad and deep generalization. Students are not just observing order but symbolically representing and manipulating generalized relationships. In this process, patterns serve as a foundation for the development of increasingly sophisticated forms of generalization. Moving from the recognition of a specific pattern to the formulation of a valid general rule, however, requires learners to coordinate different forms of mathematical reasoning and establish relationships that extend beyond the particular cases they initially observe.

The indicators employed to evaluate mathematical generalization ability in this study include perceiving generality, expressing generality, representing generality symbolically, and manipulating generality (Mason, 1996). Patterns are identified through perceiving generality. The determination of subsequent data based on identified patterns is carried out through expressing generality. The results of generalization are formulated symbolically through the symbolic expression of generality by establishing general rules, whereas learners engage in problem solving by using generalized results and manipulating generality (Mason, 1996). Understanding patterns is fundamental to the development of mathematical generalization, as it enables learners to recognize relationships, formulate general rules symbolically, and apply these rules to solve problems through increasingly sophisticated forms of reasoning.

Various strategies are used by students in the process of generalizing. The difference-finding strategy emphasizes identifying the differences observed between adjacent terms in a number pattern (Montenegro, Costa, & Lopes, 2018). Quantity-relationship strategies emphasize the connections between input values and their corresponding outputs (Ellis, 2011). In the trial-and-error strategy, every possible method is attempted to solve the problem (Becker & Rivera, 2005). The linear pattern strategy utilizes a formula that represents a linear pattern (Stacey, 1989). Visual

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strategies can be categorized into visual classing strategies and visual pattern growth strategies (Becker & Rivera, 2005). Nevertheless, recursive strategies are frequently used by students, in which the next nth term is determined based on the previous nth term (Hourigan & Leavy, 2015). Students employ various strategies in mathematical generalization, including identifying differences, recognizing patterns, analyzing quantity relationships, using visual representations, and applying recursive or linear reasoning, all of which support the development of generalized mathematical understanding. Although students can use all of these strategies when engaging with pattern-based tasks, the strategies do not necessarily indicate the same level of mathematical generalization.

2.2. Functional Thinking

Functional thinking is conceptualized as representational thinking that emphasizes the interrelationships among changing quantities (Markworth, 2010). Functional thinking is characterized by the generalization of relationships between quantities that change simultaneously, which may be expressed using words, algebraic notation, tabular representations, and graphical forms (Blanton, Stephens, et al., 2015). The emphasis of functional thinking was not on formal functions in their traditional sense. Instead, students were encouraged to generalize quantitative relationships, represent these relationships, and use the resulting representations to reason about and predict functional behavior (Krüger, 2019; Stephens et al., 2017). A defining feature of functional thinking is the ability to recognize and examine relationships among quantities (Frey, Sproesser, & Veldhuis, 2022; Raquel Martins, Viseu, & Rocha, 2023). Based on the preceding discussion, functional thinking can be understood as emphasizing the generalization of relationships among varying quantities across multiple representations, enabling learners to analyze, represent, and predict functional behavior by reasoning about patterns and quantitative relationships.

The interpretation of variables and generalization involves covariational relationships, correspondence, and the connection among various representations (Clark-Wilson, Donevska-Todorova, Faggiano, Trgalová, & Weigand, 2021; Oliveira, Polo-Blanco, & Henriques, 2021). The development of functional thinking can be supported through engagement with recursive patterns, covariational relationships, and correspondence (Blanton, Brizuela, Gardiner, Sawrey, & Newman-Owens, 2015; Pang, Kim, & Sunwoo, 2022; Stephens et al., 2017). Functional thinking can be analyzed in three ways, namely recursive patterns, relationships involving covariation, and correspondence relationships (Blanton & Kaput, 2011). The functional thinking indicators examined in this study included identifying recursive patterns, recognizing covariational relationships, and establishing relationships between corresponding quantities. Recursive patterns were assessed through students' ability to investigate objects within a pattern and determine the subsequent object in the sequence. Covariational relationships were identified based on students' ability to identify how a change in one quantity relates to a change in another quantity. In contrast, relationships between corresponding quantities were established through the generalization of the relationship between two quantities presented in a given problem. Taken together, these indicators conceptualize functional thinking as a progression from identifying local changes to coordinating covarying quantities and constructing generalized relationships. Thus, functional thinking can help students generalize, especially students in the transition stage, not only by observing patterns but also by explaining and presenting the relationships that exist in these patterns.

2.3. Higher Order Thinking Skills (HOTS)

One of the competencies that are very important for students to have when learning mathematics in the 21st century is higher-order thinking skills (Collins, 2014; Mytra, Wardawaty, Akmal, Kusnadi, & Rahmatullah, 2021). Higher-order thinking refers to cognitive processes that go beyond merely memorizing facts or repeating information exactly as it was received (Thomas & Thorne, 2009). The concept of Higher-Order Thinking Skills originates from Bloom's Taxonomy, in which higher-order cognitive processes include analyzing, evaluating, and creating, all of which require mastery of the preceding cognitive levels (Zetriuslita, Suripah, Ariawan, & Hidayat, 2023). Thus, Higher-Order Thinking Skills involve advanced cognitive processes that extend beyond memorization, encompassing

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abilities such as analyzing (examining relationships), evaluating (assessing outcomes), and creating (generating new ideas), which contribute significantly to the development of deep mathematical comprehension and effective problem-solving.

In Indonesia, the level of HOTS-based questions is determined by teachers using the classification of thinking abilities provided in the Revised Bloom's Taxonomy. The six levels of thinking abilities included in the Revised Bloom's Taxonomy are arranged from the lowest to the highest: recalling information (C1), comprehending concepts (C2), applying knowledge (C3), examining relationships (C4), assessing outcomes (C5), and generating new ideas (C6). The first three levels are generally classified as lower-order thinking skills, whereas the latter three levels are regarded as higher-order thinking skills (Gopalan & Hashim, 2021).

At the recalling information level (C1), relevant knowledge is retrieved from long-term memory through processes of recall or recognition. The comprehending concepts level (C2) requires comprehension of information and concepts, as well as the ability to explain and interpret them. At the applying knowledge level (C3), learners use acquired knowledge in unfamiliar contexts to complete tasks or solve problems. The examining relationships level (C4) requires breaking information into smaller components and analyzing the connections among them, such as investigating interactions between characters in a story. At the assessing outcomes level (C5), judgments are formed based on established criteria and available evidence, for example, justifying an imaginary judicial ruling or evaluating the merits and limitations of a particular idea. Finally, the generating new ideas level (C6) focuses on producing original ideas or creating new products, such as preparing a scientific report (Susantini, Sari, Marzuqi, & Asteria, 2025).

Consequently, HOTS and mathematical generalization are more appropriately understood as complementary rather than hierarchical constructs. The process of pattern generalization involves the cognitive processes found in the revised Bloom's taxonomy. Students analyze the relationships between elements in patterns (C4), evaluate those relationships and apply them to other cases (C5), and formulate general rules or formulas (C6). Thus, generalization and functional thinking are part of HOTS and involve complex reasoning. Therefore, learning environments that aim to foster generalization should engage students not only in recalling information and applying procedures but also in analyzing relationships, justifying conjectures, evaluating generalizations, and constructing generalized representations.

2.4. A Website-Based Application Integrating HOTS and Functional Thinking

Mobile technology has transformed science learning by allowing educational activities to occur beyond the traditional classroom setting, and it can accompany students to various places for study (Martins & Ertzberger, 2013; Zydney & Warner, 2016). Educational content and learning tools can be accessed by users at any time and from anywhere through mobile learning applications, which are designed as software platforms for learning purposes (Sun & Looi, 2016). Mobile learning extends beyond native Android and iOS applications to include various learning environments that are accessible via mobile devices, including smartphones and tablets. Its defining feature is the provision of ubiquitous learning opportunities, enabling students to interact with learning materials through mobile devices without being constrained by time or location (Lazaro & Duart, 2023). The concept of mobile learning also includes web-based learning applications accessed through mobile devices, indicating that web applications form an integral part of the mobile learning ecosystem (Ruiz-Martínez, Castañeda, & Fernández-Breis, 2022). Consequently, mobile learning provides learners with access to educational content regardless of time or location through the use of mobile technologies, extending learning beyond traditional classroom settings and encompassing both native mobile applications and web-based learning platforms accessible on mobile devices.

For this study, students can access the web-based application through a range of devices, including mobile phones and laptops. The application was developed as a mathematics learning tool to support the teaching and learning of mathematical patterns among eighth-grade junior high school students. This application has various features that

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support students in learning patterns. The features consist of a list of materials and subjects, a list of pattern tasks, a list of HOTS tasks, an assessment list, an upload section for pattern tasks, an upload section for HOTS tasks, an assessment upload section, and an assessment report.

The materials list feature provides content about mathematical patterns that students can study independently. The topic of mathematical patterns covers both number patterns and geometric patterns. The pattern tasks feature requires students to solve problems involving numerical and geometric patterns according to the instructions provided. The researcher designed the tasks in this application based on functional thinking indicators, which consist of identifying recursive patterns, recognizing covariation relationships, and determining correspondence relationships.

In the HOTS tasks feature, students work on mathematical pattern problems developed according to Higher-Order Thinking Skills (HOTS) indicators. These activities are intended to foster students' abilities in analysis, evaluation, and creation. Upon completing the pattern and HOTS tasks, students upload their responses through the pattern task upload and HOTS task upload features. The solutions to these tasks are subsequently discussed through collaborative class discussions.

After the learning process had been completed, students completed an assessment designed to measure their mathematical generalization ability. The completed assessment is then uploaded using the assessment upload feature provided within the application. Once the teacher has evaluated the students' work, the assessment results can be accessed through the student performance report feature, allowing students to monitor their learning achievements and progress. The interface of the website-based application used by students in this study is presented in Figure 1.



Figure 1. Interface of the website-based application.

3. METHOD

3.1. Research Design

The researchers implemented an explanatory sequential mixed-methods design by first collecting and analyzing quantitative data and then gathering and analyzing qualitative data to explain and enrich the quantitative findings. The subsequent integration of these two strands of data provided a more holistic understanding of the research problem (Creswell, 2021).

Accordingly, a mixed-methods approach involving quantitative and qualitative techniques was employed to examine the impact of a web-based application that integrates Higher-Order Thinking Skills (HOTS) and functional thinking on the mathematical generalization ability of junior high school students. The quantitative phase of this study employed a quasi-experimental design. Quantitative data were collected and analyzed to examine whether significant differences existed in mathematical generalization ability between students in the experimental class and those in the control class. Furthermore, students' perceptions regarding the use of the web-based application in

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mathematics learning were examined through the collection and analysis of relevant data. Semi-structured interviews were then administered to explore students' mathematical generalization abilities in greater depth and the problem-solving strategies they applied. These qualitative findings helped explain and elaborate on the quantitative outcomes, leading to a more holistic evaluation of the intervention's effectiveness.

In the experimental class, mathematics learning was conducted through a discussion-oriented instructional approach supported by a web-based application incorporating Higher-Order Thinking Skills (HOTS) and functional thinking. Students accessed the application via their own mobile devices. Meanwhile, students in the control class participated in discussion-based learning using student worksheets as the main instructional medium. The intervention was carried out during mathematics instruction on mathematical patterns for junior high school students.

3.2. Sample

Participants were recruited from two public junior high schools in East Java, Indonesia: SMP Negeri 1 Trowulan and SMP Negeri 6 Kediri. A total of 64 students from SMP Negeri 1 Trowulan (two classes) and 64 students from SMP Negeri 6 Kediri (two classes) participated in the study. All participants were 8th-grade students, and selection was conducted through class-level random assignment to maintain the continuity of the existing learning process. In each school, the selected classes were assigned to either an experimental or a control condition, yielding two experimental classes and two control classes across the participating schools.

For the qualitative stage of the study, 10 participants were selected from the total sample using a purposive sampling technique. The selection criterion was students' ability to demonstrate mathematical generalization. These students participated in interviews aimed at exploring their mathematical generalization processes and experiences during the learning activities in greater depth.

3.3. Data Collection Techniques and Instruments

Data collection involved the use of tests, questionnaires, and interviews. The instruments employed in this study comprised a mathematical generalization assessment, learning tasks, student questionnaires, interview guidelines, and a web-based application. The tests were administered to examine differences in mathematical generalization ability between students in the experimental and control classes.

Meanwhile, a questionnaire was given to students in the experimental class to determine their responses to the web-based application used for mathematics learning. To find out about the generalization process and strategies used by students, interviews were conducted.

Before data collection was initiated, all research instruments were reviewed and verified by experts to ensure their content validity. Two experts in mathematics education and educational assessment assessed the instruments based on content relevance, linguistic transparency, alignment with the research goals, and appropriateness for the intended grade level. Furthermore, the web-based application was evaluated by instructional media experts for its features and ease of use.

Following the experts' responses, revisions were made to enhance item conceptualization, increase the transparency of directions, and reinforce the alignment between the assignments and the mathematical generalization indicators, Higher-Order Thinking Skills (HOTS), and functional thinking. The experts concluded that the revised instruments sufficiently described the intended forms and were acquired for data collection. To ensure reliability, the instruments were further assessed for consistency and coherence across items. The experts verified that the items demonstrated adequate clarity and consistency in assessing the intended constructs. Consequently, the instruments were deemed valid and reliable for application in this study.

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3.4. Data Analysis Procedure

Quantitative data were analyzed using IBM SPSS Statistics Version 27, and paired-samples t-tests were employed to examine differences within each group, whereas independent-samples t-tests were utilized to examine differences in post-test performance between the experimental and control classes. Questionnaire responses were analyzed by computing students' scores and determining the average percentage score. The obtained percentages were subsequently classified based on the criteria outlined in Table 1.

Interview data were examined using an organized qualitative analysis system involving data arrangement and preparation, extensive data review, coding, the development of descriptive classifications and themes, the presentation of themes in a narrative format, and an explanation of the meaning of the findings (Creswell & Guetterman, 2019). The qualitative results are provided to elaborate on and further interpret the quantitative findings.

Table 1. Questionnaire score categories.

No.	Score Range (%)	Category
1	0 - 20	Very Poor
2	21 - 40	Poor
3	41 - 60	Adequate
4	61 - 80	Good
5	81 - 100	Very Good

Students' mathematical generalization ability was classified into three levels: high, moderate, and low. Students at the high level were able to state generalizations symbolically in the form of algebraic expressions and implement these generalizations to solve mathematical questions. This level indicates students' ability to compose general rules and use them effectively in various contexts. Students at the moderate level were able to determine patterns, control successive terms, and develop broad rules verbally. Although they established an understanding of pattern regularities, they had not yet regularly stated these abstractions using symbolic or algebraic representations. Students at the low level were able to comprehend simple patterns in given examples; however, they were unable to connect these examples to construct a complete inference, general pattern, or mathematical generalization. Their reasoning remained limited to individual cases and did not expand to broader pattern structures.

3.5. Intervention Design

During the initial meeting, the pretest was administered to participants in both the experimental and control classes. Following completion of the instructional intervention, the posttest was conducted during the final meeting. The intervention consisted of a website-based learning application designed to promote students' mathematical generalization ability through the integration of Higher-Order Thinking Skills (HOTS) and functional thinking. The learning tasks implemented in the website-based application were designed based on the principles of Higher-Order Thinking Skills (HOTS) and functional thinking. The tasks included numerical patterns and geometric pattern activities that were aligned with the indicators of functional thinking, such as identifying relationships between variables, recognizing patterns, and formulating general rules. Students engaged in pattern-based activities involving analysis, evaluation, and creation, reflecting key dimensions of HOTS. The intervention was conducted in the experimental class over two weeks, during which students actively engaged in application-based learning activities and completed the assigned tasks.

Students first studied the materials provided through the web-based application. The teacher reinforced their understanding through classroom explanations and guided discussions. Students then worked collaboratively with their seatmates to complete the assigned tasks. The collaborative activities encouraged students to discuss problem-solving strategies, identify patterns, and formulate mathematical generalizations. Subsequently, students presented the results of their discussions to the class. The teacher then facilitated class discussions by providing feedback,

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clarifying misconceptions, and reinforcing key mathematical concepts. Additional explanations were provided whenever students' presentations revealed incomplete or unclear reasoning.

In contrast, students in the control class engaged in learning activities supported by student worksheets addressing the same mathematical topic over an equivalent two-week period. In the control class, students completed the student worksheets under the teacher's guidance. Similar to the experimental class, the learning process incorporated collaborative discussions and class presentations. Students engaged in paired collaborative activities to solve the worksheet tasks and shared their solution strategies through peer discussions. Subsequently, students presented the results of their discussions to the class. During these activities, the teacher facilitated the discussions, provided constructive feedback, and addressed students' errors to enhance their understanding of the underlying mathematical concepts.

4. RESULTS

4.1. Quantitative Results

The topic of mathematical patterns was taught in both the experimental and control classes through five learning sessions. In the experimental class, students engaged with a web-based application incorporating Higher-Order Thinking Skills (HOTS) and functional thinking, which they accessed through their mobile devices. Meanwhile, students in the control class learned primarily through student worksheets. Before the intervention was carried out, students were given a pre-test to determine their baseline level of mathematical generalization ability. After the learning process was completed, the researchers administered a post-test to assess changes in students' mathematical generalization ability.

As presented in Table 2, the experimental and control classes had pretest mean scores of 47.50 and 49.69, respectively. After the intervention, the average posttest score of the experimental class increased to 81.56, while that of the control class increased to 55.23. This represents a 34.06-point improvement in the experimental class, compared with only 5.54 points in the control class. These results suggest that students who engaged with the web-based application incorporating HOTS and functional thinking achieved greater improvements in mathematical generalization ability than those who learned through conventional worksheets.

Table 2. Descriptive Statistics of Pre-Test and Post-Test Scores.

Test	Class	N	Mean	Std. Deviation	Std. Error Mean
Pre-test	Experimental class	64	47.50	9.43	1.18
	Control class	64	49.69	9.88	1.23
Post-test	Experimental class	64	81.56	11.16	1.39
	Control class	64	55.23	12.00	1.50

The Kolmogorov–Smirnov test was used to assess the normality of the data distribution, considering that the number of participants was greater than 50. As presented in Table 3, the experimental class's pre-test scores (D = 0.105, p = 0.079) and the control class's pre-test scores (D = 0.104, p = 0.080) were normally distributed because their p-values were greater than 0.05. The post-test scores similarly met the criterion for normality, with D = 0.105 and p = 0.075 for the experimental class and D = 0.107 and p = 0.064 for the control class. Consequently, the normality assumption was satisfied in both classes.

Table 3. Test of normality.

Kolmogorov-Smirnov				
	Class	Statistic	df	Sig. (p-value)
Pre-test	Experimental class	0.105	64	0.079
	Control class	0.104	64	0.080
Post-test	Experimental class	0.105	64	0.075
	Control class	0.107	64	0.064

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The results presented in Table 4 indicate that the pre-test score distributions met the homogeneity of variance assumption, as verified by Levene's test for the experimental and control classes, $F(1, 126) = 0.148$, $p = 0.701$. As the significance value exceeded 0.05, the pre-test scores met the assumption of equal variance. Similarly, the post-test scores showed homogeneous variance across the experimental and control classes, $F(1, 126) = 0.530$, $p = 0.468$. As the significance value was greater than 0.05, the post-test scores were considered to meet the assumption of equal variance. These results indicate that the homogeneity assumption required for subsequent parametric analyses was fulfilled for both the pre-test and post-test scores.

Table 4. Test of homogeneity of variances.

Test	Basis	Levene Statistic	df1	df2	Sig. (p-value)
Pre-test	Based on Mean	0.148	1	126	0.701
Post-test	Based on Mean	0.530	1	126	0.468

As reported in Table 5, the experimental class showed a mean difference of 34.06 points between the pre-test and post-test assessments, whereas the control class showed a mean difference of 5.547 points. The corresponding standard deviations were 14.444 and 15.964, respectively. Both classes demonstrated score gains between the pre-test and post-test. Greater improvement was achieved by the experimental class than by the control class.

The findings also demonstrated a statistically significant gain in the experimental class's performance between the pre-test and post-test assessments, $t(63) = 18.866$, $p < 0.001$. Moreover, the effect size, as measured by Cohen's d, was very large ($d = 2.358$). This finding indicates that the website-based application integrating Higher-Order Thinking Skills (HOTS) and functional thinking significantly enhanced students' mathematical generalization ability.

Table 5. Paired-samples t-test results.

Class	Comparison	Mean Difference	Std Deviation	Std. Error Mean	t	df	Sig. (p-value)	Cohen's d
Experimental class	Pre-test & Post-test	34.062	14.444	1.806	18.866	63	< 0.001	2.358
Control class	Pre-test & Post-test	5.547	15.964	1.996	2.780	63	0.007	0.347

The findings from Levene's test demonstrated that the data fulfilled the assumption of equal variances, $F(1, 126) = 0.53$, $p = 0.468$, as the significance value exceeded 0.05. The post-test scores were analyzed using an independent-samples t-test to determine the differences in mathematical generalization ability between the two classes. A statistically significant difference between the experimental and control classes was identified, as presented in Table 6, $t(126) = 12.854$, $p < 0.001$. Therefore, it can be concluded that students in the experimental class demonstrated significantly higher mathematical generalization ability than those in the control class. The mean difference between the classes was 26.328 points in favor of the experimental class. Furthermore, the effect size was very large (Cohen's $d = 2.272$), indicating that the website-based application integrating Higher-Order Thinking Skills (HOTS) and functional thinking had a meaningful impact on the development of students' mathematical generalization ability. Changes in students' mathematical generalization abilities can be found in Table 7.

Table 6. Independent-samples t-test results.

Comparison	Levene's test for equality of variances		Mean Difference	t	df	Sig. (p-value)	Cohen's d
	F	Sig.					
Post-test of experimental and control classes	0.530	0.468	26.328	12.854	126	< 0.001	2.272

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Table 7. Mathematical generalization ability.

Class	Pre-test			Post-Test		
	High	Moderate	Low	High	Moderate	Low
Experimental class	0%	15.63%	84.37%	65.63%	21.87%	12.5%
Control class	0%	37.5%	62.5%	0%	45.31%	54.69%

Students' perceptions of the implementation of the website-based application were gathered through a questionnaire administered after the intervention. The instrument comprised 10 statements evaluated using a four-point Likert scale. The results of the questionnaire are summarized in Table 8.

Table 8. Results of student response questionnaire.

No.	Statement	Average Score	Percentage	Criteria
1	The website-based application is engaging to use for learning	3.297	82.42%	Very Good
2	The interface of the website-based application is visually appealing	3.094	77.34%	Good
3	The website-based application is easy to use	3.188	79.69%	Good
4	The instructions provided are easy to understand	3.109	77.73%	Good
5	The learning materials and tasks provided in the website-based application are easy to understand	3.094	77.34%	Good
6	The tasks are aligned with the learning materials	3.313	82.81%	Very Good
7	The language used in the website-based application is easy to understand	3.25	81.25%	Very Good
8	I enjoy learning through this website-based application	3.172	79.3%	Good
9	The website-based application includes practice activities designed to develop Higher-Order Thinking Skills (HOTS)	3.391	84.77%	Very Good
10	The website-based application is easily accessible	3.188	79.69%	Good

Based on the table of responses from eight students regarding the application that integrates HOTS and functional thinking, the students gave positive responses overall. The students' responses fell into the good and very good categories for all the statements on the questionnaire. The statement with the highest rating (84.77%, very good) was "This website-based application contains exercise activities designed to develop Higher-Order Thinking Skills (HOTS)." These findings show that the integration of HOTS-based assignments was well received and contributed positively to the students' learning experience.

Similarly, the students' response regarding the assignments' accordance with the learning material was 82.81%. This shows that the tasks given can provide a meaningful theoretical understanding. The students' responses regarding the applications' interest for learning and the language used in the application were 82.42% and 81.25%, respectively (very good category). The findings from this application can increase students' motivation to learn mathematics.

Student responses concerned aspects of visual appeal (77.34%), ease of use (79.69%), clarity of instructions (77.73%), readability of learning materials and assignments (77.34%), learning comfort (79.30%), and accessibility (79.69%). This shows that students respond positively to the application in terms of attractiveness, accessibility, and ease of use, and that it supports learning activities that encourage HOTS. Thus, this application can improve meaningful learning experiences and students' higher-order thinking skills.

4.2. Qualitative Results

Several themes about the use of this website-based application were revealed through interviews. At first, students focused only on partial cases and lacked an understanding of the concept of the nth term or the general form of a pattern. However, through engagement with HOTS-oriented and functional thinking activities, students

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gradually identified regularities and relationships between quantities, enabling them to recognize the nth term and formulate general rules. Students' ability to express generalized relationships algebraically increased, enabling them to manipulate representations and use symbolic expressions to solve mathematical problems. Students used functional thinking indicators when applying strategies to generalize geometric patterns. Based on the interviews, students were able to determine the nth term of number and geometric patterns. In addition, students also responded positively to this application. Overall, these findings indicate that HOTS-oriented applications and functional thinking can improve students' generalization abilities and activity in learning. The thematic integration of students' perspectives is summarized in Table 9.

Table 9. Thematic integration of student perspectives (n = 10).

Theme	Subtheme	Sample Quotes
1. Understanding of Mathematical Patterns	Understanding of nth-Term Patterns	"The nth pattern represents the number of balls that can be produced within n hours." (S1) "The nth pattern refers to the nth model; for example, it may represent the 15th, 20th, or any subsequent pond model." (S2)
2. Strategy	Recursive strategy Inductive strategy	"The number of balls produced in 6 hours can be determined from the number produced in 5 hours. Since 500 balls are produced in 5 hours, adding 100 results in 600 balls, because production increases by 100 balls each hour." (S3) "To determine the number of white and blue tiles required for the fourth pond model, i examined the numbers of white and blue tiles in the first, second, and third models. For the blue tiles, model 1 contains =1×1=1 tile, model 2 contains 2×2=4 tiles, and model 3 contains 3×3=9 tiles. Therefore, model 4 contains 4×4=16 blue tiles. For the white tiles, model 1 contains 1×4+4=8 tiles, model 2 contains 2×4+4=12 tiles, and model 3 contains 4×4=16 tiles. Therefore, model 4 contains 4×4+4=20 white tiles." (S4)
3. Ability to Express Generalizations Symbolically	Formulating the nth-Term Rule in Algebraic Form	"The number of balls that can be produced in n hours is (100n)." (S3) "The number of blue tiles in the nth pond model is (n^2)." (S4) "The number of white tiles in the nth pond model is (4n + 4)." (S4)
4. Positive Learning Experiences	Learning Flexibility	"I can download the learning materials and assignments from the website-based application, so I can review them again whenever I do not fully understand the content." (S1) "I can read the learning materials and assignments anywhere without having to carry a textbook." (S3)

4.3. Integrated Synthesis of Findings

Based on the results of this study, a website-based application that integrates HOTS and functional thinking can effectively improve students' mathematical generalization skills and increase students' motivation to learn mathematics. The quantitative findings show that the improvement in the generalization ability of the experimental class is greater than that of the control class. There was an increase of 34.06 points in the experimental class and 5.54 points in the control class. The independent-samples t-test showed a statistically significant difference in mathematical generalization ability between the two groups, $t(126) = 12.854$, $p < 0.001$. Qualitative findings based on interviews with students in the experimental class after using the application showed that the students had a strong understanding of n-syllables, used recursive and inductive reasoning strategies, and were increasingly able to express abstract relationships through algebraic representations. This can be seen from the students' ability to

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determine "the number of balls produced in n hours is 100n" (S3), "the number of blue tiles in the n pond model is n^2" (S4), and "the number of white tiles in the n pond model is (4n + 4)" (S4). The findings of the questionnaire showed that students' responses to the application were very positive; they found the application attractive, accessible, user-friendly, and supportive of learning. The combined presentation of the quantitative and qualitative findings is provided in Table 10.

Table 10. Integrated results display.

Quantitative Findings	Qualitative Findings	Integrated Interpretation
Independent-Samples t-Test Results $t(126) = 12.854$, p-value < 0.001	Students demonstrated better pattern recognition and rule formulation during interviews and post-tests.	HOTS and Functional thinking tasks promoted the development of symbolic reasoning necessary for mathematical generalization.
The questionnaire findings showed that students responded positively to the website-based application.	Students emphasized the flexibility, accessibility, and interactive learning experience provided by the website-based application.	Positive learning experiences enhanced student engagement and supported the effective implementation of the intervention.

5. DISCUSSION

For the first research question, the findings of the independent-samples t-test confirmed a statistically significant difference in mathematical generalization ability between students in the experimental and control classes. Additionally, the very large effect size (Cohen's d = 2.272) provides strong evidence that the web-based application incorporating HOTS and functional thinking effectively enhanced students' mathematical generalization ability. The findings reinforce and extend previous research, which reported that technology-based learning media positively influence students' academic achievement (Canbaz & Yalçın, 2024). The present study differs from the previous research in several aspects. First, the technology-based learning medium employed in the previous study was based on augmented reality, whereas the current study utilized a website-based application integrating Higher-Order Thinking Skills (HOTS) and functional thinking. Second, the outcomes investigated in the previous study focused on students' attitudes and academic achievement, while the present study examined the improvement of students' mathematical generalization ability. Accordingly, previous research has drawn attention to the benefits of technology-enhanced learning environments; the present study contributes to the literature by providing empirical evidence that a web-based application incorporating HOTS and functional thinking can enhance students' mathematical generalization ability.

Regarding the second research question, students responded positively to the website-based application. Students responded very positively to this website-based application in terms of the application's attractiveness, the suitability of the materials and assignments, and the clarity of the language, which encouraged higher-order thinking skills. These findings are consistent with the Technology Acceptance Model (TAM), which explains that technology acceptance is largely shaped by users' perceptions regarding its usefulness and ease of use (Schorr, 2023). The positive responses suggest that students perceived the application as both useful for supporting mathematics learning and easy to use, thereby contributing to its successful implementation.

The third research question was explored through the examination of students' post-test performance and interview data. The findings revealed that the experimental class experienced greater improvement in mathematical generalization ability than the control class. These improvements were reflected in students' enhanced understanding of the nth term, their use of recursive and inductive reasoning strategies, and their ability to formulate generalizations using algebraic symbols and expressions. Such findings reinforce and extend previous research, which argued that mathematical understanding can be enhanced through the embedding of digital applications within learning activities (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014). Previous research has shown that integrating information and communication technology (ICT) can significantly improve students' mathematical competencies, conceptual

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understanding, and academic achievement (Hernández-Martínez, Posso-Yépez, Cadena-Povea, Rivadeneira-Flores, & Placencia-Enríquez, 2025). The present study extends this work by incorporating Higher-Order Thinking Skills (HOTS)-oriented tasks and functional thinking activities into a website-based learning application designed to strengthen students' mathematical generalization ability. In contrast to previous research, this study integrates both HOTS-based tasks and functional thinking activities as complementary components of the learning intervention.

6. CONCLUSION

Based on the findings of this study, it is shown that the website-based application integrating Higher-Order Thinking Skills (HOTS) and functional thinking is effective in improving students' mathematical generalization skills. The increase in mathematical generalization ability in the experimental class is greater than that in the control class. Improvements in mathematical generalization skills include identifying patterns, determining the relationships among the existing patterns, and making formulas (general rules) algebraically. Students also responded very positively to the application in learning. In theory, the results of this study contribute to the existing wealth of knowledge by showing how a website-based application that integrates Higher-Order Thinking Skills (HOTS) and functional thinking can improve students' mathematical generalization skills. This approach can be applied across different mathematical topics, grade levels, and educational contexts. Practically, the findings suggest that a web-based application can serve as an effective tool for promoting higher-order mathematical thinking and improving students' engagement in mathematics learning. Further study can be conducted by exploring these applications with specific learning models and developing applications for a variety of other mathematics materials.

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