International Journal of Innovative Research and Scientific Studies, 8(2) 2025, pages: 1821-1832

IJIRSS
International Journal of Innovative Research & Scientific Studies

ISSN: 2617-6548

URL: www.ijirss.com

Development of Educational Research on Integrated Combinatorial-Thinking learning model: Combinatorial thinking skills

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Abstract

This study aims to develop and test the ERIC (Educational Research on Integrated Combinatorial-Thinking) learning model to improve students' combinatorial thinking skills in mathematics learning. Using a Research and Development (R&D) approach modified from the Borg & Gall design, this study involved expert validation, limited trials, as well as analysis of the validity, practicality, and effectiveness of the model through a combinatorial thinking skills test and a student response questionnaire. The results showed that the ERIC model was valid, with an average score of 3.737 from three validators. The model's practicality was rated very good, with the implementation rate reaching 95.67% and student activity averaging 94.85%. The model's effectiveness can be seen from the students' achievement in combinatorial thinking, with the highest score on the indicator "identifying several problems" (98.33%). Student response to learning was also very positive, with 97.6% giving positive responses. The ERIC learning model integrates Problem-Based Learning (PBL) elements with combinatorial thinking indicators, creating a systematic, collaborative, and creative approach. This model improves students' ability to solve mathematical problems and prepares them to face real-world challenges more effectively and innovatively. The ERIC learning model can be implemented in mathematics learning to enhance students' combinatorial thinking skills, which are essential for solving complex problems and applying mathematical logic in real-life situations. Additionally, this approach helps lecturers guide students more effectively through discussion-based and collaborative learning strategies.

Keywords: Combinatorial Thinking Skills, Critical Thinking, ERIC learning model, Learning, Thinking Skills, Mathematics Learning. Problem-Based Learning, Science.

DOI: 10.53894/ijirss.v8i2.5552
Funding: This study received no specific financial support.
History: Received: 3 February 2025 / **Revised:** 6 March 2025 / **Accepted:** 12 March 2025 / **Published:** 21 March 2025

Competing Interests: The authors declare that they have no competing interests.
Authors' Contributions: All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.
Transparency: The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.
Acknowledgment: We gratefully acknowledge the support of the Mathematics Education Postgraduate Study Programme.
Publisher: Innovative Research Publishing

1. Introduction

In this era of information and globalization, one must have the ability to think creatively. This ability allows you to generate various ideas and ideas and implement them in products that are beneficial to the community, state, nation, and country. To solve problems faced with ever-evolving changes, one must have the ability to think creatively. Learning in the 21st century must be trained to think critically, think creatively, work together, and communicate.

In today's education, an educator is not just an information disseminator or facilitator. Learning should go beyond the physical boundaries of the classroom, and educators need to be the designers of the learning environment [1]. Education affects the skills and patterns of human thinking [2]. One of the things that can be done to achieve these goals is continuous renewal in the field of education, especially mathematics subjects [3].

Mathematics education is a field of study concerned with teaching, learning, and understanding mathematics. Mathematics education includes theories for learning and teaching mathematics and developing effective mathematics curricula and models. The vision of mathematics education in Indonesia is devoted to understanding mathematical concepts and ideas, which are then applied in routine and non-routine solutions through the development of mathematical reasoning, communication, and connections [4]. Students are expected to be able to use mathematics and mathematical thinking in everyday life and learn various information that emphasizes the preparation of logic, character building, and the ability to apply mathematics. As cited by Setianingsih, et al. [5] NCTM states that mathematics learning is considered a social effort where the mathematics classroom acts as a community that encourages students to think, discuss, agree, and disagree. Learning mathematics requires not only counting but also logical thinking and reasoning skills. Lay [6] stated that in Piaget's theory of mental development through the Test of Logical Thinking (TOLT), logical thinking includes: (1) controlling variables, (2) CTM states that combinatorial thinking is an essential element compared to other types of logical thinking and its existence cannot be separated from mathematics [7, 8].

Combinatorial thinking combines expressions/formulas, calculation processes, and results/conclusions; the three processes are interconnected and take place systematically [9]. Combinatorial thinking opens the door for imagination and logic to come together to investigate unique and creative possibilities in mathematics. Combinatorial thinking skills can also be used in decision-making, planning, and experimental design. Combinatorial thinking skills can develop the ability to solve more complex problems and improve their critical and creative thinking skills. Using combinatorial thinking in combinatorial situations means developing a unique ability to create abstract models and find the structure of a set of results [10]. The importance of combinatorial thinking will be more visible when students follow the learning process and work on problems [5].

Five indicators influence combinatorial thinking skills. Each indicator has several different sub-indicators [11]. The indicators of combinatorial thinking skills are identifying multiple problems, understanding problem patterns, applying mathematical patterns, and using mathematical proof to consider multiple combinations of other problems. Understanding the indicators and sub-indicators of combinatorial thinking skills can develop the ability to solve combinatorial problems more effectively and efficiently. Combinatorial thinking is a tool to solve problems if students perform tasks. Students must use their combinatorial thinking and find systematics to ensure that all possibilities have been discussed [12]. Combinatorial thinking considers all possible alternatives in a given situation [13]. Combinatorial thinking is important because it is an essential thinking ability that must be continuously developed towards critical thinking abilities and skills. However, many students need help with combinatorial thinking [14, 15].

The results of research conducted by Ammamiaritha and Surya [13] show that students' ability in combinatorial thinking is still relatively low. Meanwhile, according to Salavatinejad, et al. [16] there are several types of errors that often occur when students solve combinatorial problems, including: a) sequence-related errors, which occur when students cannot determine whether the order of objects or events in a combinatorial task is important or not; b) errors in understanding repetition, namely the inability to recognize whether repetition in the problem is allowed; c) inability to distinguish, which arises when students cannot distinguish whether the objects in the problem are distinguishable or not; d) calculation errors, either due to over- or under-counting, so that some modes are calculated more than once or even not calculated at all; e) formula application errors, which occur due to a lack of conceptual understanding of combinatorial formulas, so that students cannot choose the right formula or use it correctly; and f) generalization errors, where students are unable to apply the solution of a problem to other similar situations.

The highest combinatorial thinking ability of students is identifying several problems (96%), while the lowest is considering several combinations of other problems (34.16%) [17]. Understanding the nature of students' difficulties when solving combinatorial problems can help teachers/lecturers identify how they can help students develop their combinatorial thinking [14]

Based on the above, developing a model that can train problem-solving and ultimately develop combinatorial thinking skills is necessary. However, some steps can maximize the role of lecturers as mediators and facilitators to facilitate positive dependence in classroom learning interactions that will encourage students to train in combinatorial thinking. One of the learning models that leads to combinatorial thinking skills is the Problem-based Learning model. Problem-based learning (PBL) is one of the learning models that can be used to develop problem-solving [18, 19]. PBL encourages skills that contribute to problem solving [20]. PBL is designed to direct students' thinking, problem-solving, and intellectual abilities [21]. Some of the advantages obtained through PBL are that students are actively involved in exploring their learning experiences [19, 22] instilling the ability to think flexibly and become successful problem solvers [22] and involving collaboration [19, 22]. Thus, PBL is a learner-centered learning through meaningful activities to develop thinking and collaboration skills.

PBL also has some disadvantages, including teachers having difficulties in increasing students' motivation, difficulties in making students concentrate on learning tasks, difficulties in helping students connect new content with prior knowledge, and difficulties in conducting cooperative learning activities efficiently [23-26]. Further research by Chin [27] revealed that the weaknesses of PBL are that it is confusing for some students at first; some students hesitate to discuss their thoughts about the problem, and it is difficult for teachers to organize open-ended problems for the learning process. The weaknesses of PBL are important indicators that exist in combinatorial thinking. Therefore, developing a learning model that can complete problem-solving and ultimately develop students' combinatorial thinking is necessary.

Combinatorial thinking skills are essential in mathematics education, including identifying patterns, creating abstract models, and developing innovative solutions. However, previous research shows these skills still need to improve among university students. Many students need help identifying problems, distinguishing elements in problems, and understanding combinatorial concepts in depth. The errors that often occur include the inability to recognize patterns, calculation errors, and improper generalization of solutions. The problem-based learning (PBL) model has been widely used to improve critical and collaborative thinking skills. However, PBL has drawbacks, such as lecturers' difficulties in managing group discussions, increasing student motivation, and ensuring consistency of understanding among students. These challenges indicate the need for a more structured and focused learning model, particularly in training combinatorial thinking skills.

Due to these limitations, developing a more integrated and specific learning model is needed to address the shortcomings of PBL, particularly in training combinatorial thinking skills. The ERIC (Educational Research on Integrated Combinatorial-thinking) Learning Model is proposed to address this need and is designed to address this gap by integrating PBL elements and combinatorial thinking indicators. The model offers a systematic approach through five phases: problem identification, investigative approach, collaboration and discussion, problem-solving, and analysis and evaluation. ERIC also emphasizes the active role of lecturers as facilitators and mediators to create positive interdependence among students, which is the foundation for effective collaboration and deep learning. The ERIC Learning Model emphasizes combinatorial thinking, which focuses on solving complex problems and the integration of structured, creative, and analytical thinking skills to create innovative solutions.

By developing the ERIC Learning model, it is expected that students not only master academic knowledge but also develop combinatorial thinking skills that allow them to combine different elements, generate new ideas, and solve problems more efficiently and effectively. This will improve students' skills in dealing with real-world problems more comprehensively and creatively.

2. Methods

2.1. Type of Research

This type of research is research and development (R&D) because this research develops and produces an ERIC (Educational Research on Integrated Combinatorial-Thinking) learning model to train students' combinatorial thinking skills as a valid, practical, and effective product.

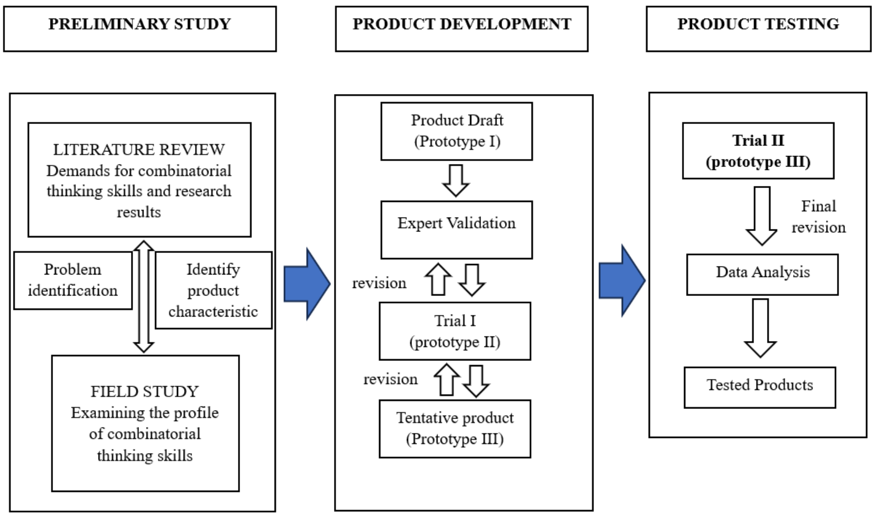

Figure 1.
Design steps of the development model adapted from Borg and Gall [28].

This study also developed learning tools as an operational form of the ERIC model, namely the ERIC model book, student assignment plan, student worksheet, student combinatorial thinking ability test sheet, student activity observation sheet, student response questionnaire, and observation sheet of learning implementation with related models. The development of the ERIC model refers to the design of the Research and Development research model, according to Borg and Gall [28]. The development steps consist of 3 main steps, namely, 1) preliminary study, 2) product development, and 3) product testing. The steps of the Borg and Gall [28] product development model were modified according to the field's needs, objectives, and conditions. The steps used are depicted in Figure 1

2.2. Research Subjects

In the development of the ERIC Learning model, three experts were involved, namely lecturers from the Department of Mathematics Education at Sebelas Maret University, Wisnuwardhana University Malang, and Insan Budi Utomo University Malang, to determine validity, furthermore, at the ERIC learning model trial stage involved 20 Mathematics Education students at PGRI Argopuro University in Jember.

2.3. Research Variables

The primary variable in this study is the ERIC *(Educational Research on Integrated Combinatorial-Thinking)* learning model. Other variables that need to be considered or involved in the development of the ERIC *(Educational Research on Integrated Combinatorial-Thinking)* learning model are (1) Product validity variables, which include the validity of the ERIC learning model, and the validity of the ERIC model learning device (2) ERIC model practicality variables consisting of ERIC model implementation, student activity (3) ERIC model effectiveness variables consisting of student combinatorial thinking skills and student responses.

2.4. Research Development

The learning model to be developed in this study is ERIC (*Educational Research on Integrated Combinatorial Thinking*) to train students' combinatorial thinking. The development stage of the learning model by modifying the Borg & Gall research and development design. In this study, it was carried out until the trial stage. The stages of developing the ERIC learning model to train combinatorial thinking are as follows:

a. Preliminary study stage: This stage aims to identify and analyze the problems that become the basis for developing a mathematics learning model to train students' combinatorial thinking skills. The activities carried out at this stage focus on gathering as much information as possible through literature study, consultation, and direct observation. Literature study was conducted by reviewing relevant research and related literature review. Consultation was conducted to obtain information about field conditions and get guidance from experts or resource persons. Meanwhile, direct observation was conducted to understand the real situation in the field regarding the profile of mathematics learning that will be the object of research.
b. Product Development Stage: This stage was conducted based on the results of analysis and findings from problem identification and product characteristics in the preliminary study. At this stage, researchers designed the initial draft of the product in the form of prototype I, namely the ERIC Learning Model designed to train students' combinatorial thinking skills. In addition, researchers also compiled learning tools which included student task plans and student worksheets as operational tools to support the implementation of the ERIC model. Researchers also developed various research instruments, such as combinatorial thinking skills test, student activity observation sheet, student response questionnaire, and learning implementation observation sheet, which served as data collection tools. After the initial draft (prototype I) was completed, the next stage was the validation process by experts to assess the feasibility of the learning model and its supporting devices. The results of this validation are used to improve the product to produce prototype II which has been validated and declared valid. Furthermore, the revised product based on expert input was tested to assess its effectiveness.

2.5. Data Analysis Technique

a. Validation analysis: Validation analysis was conducted to analyze (1) the validity of the learning model, (2) the validity of the learning device, as well as the validity of the Observation sheet and assessment. The data were analyzed using qualitative descriptive analysis.
b. Practicality Analysis: the practicality of the ERIC model, which consists of implementing the ERIC model and student activities. Implementing learning activities using the ERIC learning model was analyzed descriptively and quantitatively. Student activity observation data were analyzed descriptively and quantitatively.
c. Effectiveness analysis: Data on student responses and combinatorial thinking were analyzed descriptively and quantitatively. Data analysis of students' responses in following the learning prophesized positive and negative responses.

3. Findings

3.1. ERIC Learning Model Development (Educational Research on Integrated Combinatorial-Thinking)

The data obtained in the development of the model consists of research and information-gathering stages, expert validation, and limited-scale field trials. In the initial stage, observations of the mathematics learning process were made about how student activities were during the learning process. The observations also found that the low combinatorial thinking skills occurred because, in learning, the lecturer had not deliberately fostered positive dependence among students in learning that would encourage students to communicate and collaborate, which could train and develop students' combinatorial skills. Observations of the learning process that occurs in the classroom show that students are not encouraged to develop combinatorial thinking skills, and there need to be lecturer steps that can facilitate positive dependence among students. In addition, from the existing learning model, there is no step that deliberately facilitates students to train in combinatorial thinking. Based on the above, it is necessary to develop a learning model that can implement the category of active learning, namely 1) there are different roles among students in their groups, 2) there is a positive dependence among students, 3) the lecturer plays a maximum role as a mediator and facilitator in addition to being a guide. Based on the empirical study above, the lecturer has yet to play a maximum role as a mediator and facilitator to mediate and facilitate. Hence, there is a high positive dependence among students. In the model, there needs to be a step that forces the teacher to act as a mediator and facilitator to facilitate student combinatorial thinking. The development of the learning model developed is named the ERIC learning model.

ERIC Model development is based on results from field and literature studies. Model development is constructivism supported by model prototypes in the form of model books, learning tools, and research instruments, including Student Task Plans, LKM, student combinatorial thinking tests, ERIC model implementation sheets, student response sheets, interview sheets, and student activity sheets. The model development procedure is made by compiling a prototype. The results of the model development can be seen in Table 1.

Table 1.
ERIC (Educational Research on Integrated Combinatorial-thinking) learning model development results.

Theoretical Foundation	The theoretical foundation of ERIC learning model development consists of a philosophical, psychological, and sociological foundation. The main philosophical foundation of the ERIC learning model is constructivism in learning. Theories include those of Piaget [29] and Vygotsky [30]. The ERIC model also adheres to the pragmatic school pioneered by John Dewey, who stated that effective learning occurs when students engage in direct experiences that relate to their lives. Psychologically, ERIC is built on Piaget's theory of cognitive development. The ERIC learning model is also built on Bruner's cognitive theory, information processing theory, and Abraham Maslow's theory of humanism. The sociological foundation of the ERIC Learning model is built on Vygotsky's social learning theory and Bandura's sociocultural perspective.
Learning Syntax	In the Learning Syntax of the ERIC model, there is a syntax of the *Problem-based Learning* model and indicators of combinatorial thinking. Based on the syntax of PBL and combinatorial thinking indicators, the integration or combination of PBL models and combinatorial thinking indicators is obtained. The integration resulted in 5 syntax stages: problem identification, investigative approach, collaboration and discussion, problem-solving, analysis, and evaluation.
Social system	The social system in the ERIC model aims to create an environment that supports collaboration, respects differences and builds students' social and emotional skills. The social system states the pattern of relationships between students, lecturers, and the learning environment. Here are some elements of the social system, including a. students are proactive in learning activities by contributing to the collaborative investigation process to train combinatorial thinking skills; b. cooperation or mutual cooperation; c. lecturers carry out their role as mentors, moderators, facilitators, consultants, and mediators in the learning process to create positive dependence among students by fostering empathy for high-ability students and fostering courage in low-ability students so that communication and collaboration between students occur to solve problems in investigative activities; d. the ERIC learning model encourages an inclusive environment, respecting differences, and building social and emotional skills among students. The ERIC learning model encourages creating an inclusive environment where every student feels supported in the learning process.
Reaction principle	This reaction principle relates to how lecturers pay attention to and treat students, including lecturers responding to responses, answers, questions, or what students do. In this developed learning model, the role of the teacher is a facilitator. Here are some key aspects of the lecturer's role as a facilitator in learning using the ERIC learning model: a. facilitative approach; b. encouraging collaborative discussion; c. providing support and guidance; d. building independence in thinking, e., guiding reflection and self-evaluation
Support System	The *support system* includes all equipment, materials, and tools needed to implement the

	designed learning model. The learning process using the ERIC learning model requires various resources as a support system to support students with different learning styles and ability levels. The support system in the ERIC learning model is a learning tool that refers to the ERIC learning model (Student Task Design, LKM, student learning outcomes evaluation instruments, combinatorial thinking skills assessment instruments)
Instructional and accompanying effects	Every learning model must have instructional and accompanying impacts. The ERIC learning model considers students as subjects in the learning process. Lecturers shift from their role as knowledge givers to their role as facilitators. Lecturers encourage students to learn more focused and effectively by providing various learning tools. Students can practice thinking skills by directing their discussions and giving them the opportunity to choose problems and find solutions that suit their interests. This allows students to solve problems by independently understanding each mathematical concept or principle. This can improve their combinatorial thinking skills. The accompanying impacts include combinatorial thinking skills, students' positive motivation and response to learning, the formation of positive dependency in students, and the fostering of students' sense of empathy and courage.

The syntax of the ERIC Learning Model (*Educational Research on Integrated Combinatorial-thinking*) is detailed as follows:

3.1.1. Phase I Problem Identification

Lecturers help students find problems or challenges that must be solved by presenting problems in the form of cases, stories, or real situations. Vygotsky's Zone of Proximal Development (ZPD) concept highlights the importance of intervention from lecturers or facilitators in helping students solve problems relevant to their development level [30]. Lecturers ask more in-depth questions, thus encouraging students to evaluate the problem. Lecturers wait to provide answers but encourage them to think critically and research further.

3.1.2. Phase II Investigative Approach

Lecturers encourage students to conduct investigations and research using combinatorial thinking to explore various points of view and potential solutions. Lecturers act as facilitators to guide students in investigating problems or topics that have been identified in the previous stage. Students are trained to know how they solve problems and the strategies used in the investigation [31].

3.1.3. Phase III Collaboration and Discussion

Lecturers encourage students to share thoughts and ideas collaboratively and use combinatorial thinking to design creative solutions. Johnson and Johnson [32] suggest that collaborative learning has many benefits, including improving concept understanding, critical thinking skills, and retention.

3.1.4. Phase IV Problem Solving

The lecturer encourages students to develop concrete solutions to the problem, considering the various possibilities of combinatorial thinking.

3.1.5. Phase V Analysis and Evaluation

Lecturers help students use predetermined criteria to evaluate the solutions implemented in problem-solving. Lecturers ask reflective questions that encourage students to think critically about what works and does not work in their solutions. According to Paul and Elder [33] Critical Thinking Theory states the importance of analyzing, evaluating, and reconstructing thoughts to achieve better understanding and wiser decisions.

3.2. Validity of the ERIC (Educational Research on Integrated Combinatorial-thinking) Learning Model

The ERIC Learning Model (*Educational Research on Integrated Combinatorial Thinking*) was compiled as a model book. The ERIC Learning Model developed was validated by three experts before being tested both in content and construction. The results of the validation scores carried out by three validators of the ERIC learning model can be seen in Table 2.

Table 2.
ERIC learning model validation results.

No.	Aspects assessed	Average Rater Score			Average Validator Score	
		V_1	V_2	V_3		
1	Introduction	3.67	3.33	3.67	3,557	
2	Theoretical Foundation	3.4	3.6	3.8	3,6	
3	Contents of the ERIC Model					
	a. Syntax	4	3.8	3.8	3,867	
	b. Reaction Principle	4	3.8	3.8	3,867	
	c. Social System	4	3.8	3.8	3,867	3,872
	d. Support System	4	3.8	4	3,93	
	e. Instructional impact and supporting impact	4	4	3.5	3,83	
4	Language	4	3.75	4	3,918	
Average of all aspects (V_a)					3,737	
Criteria for validity					Valid	

Based on Table 2 the average score of the three validators for the ERIC learning model is 3.737. This shows that the ERIC learning model developed by researchers has met the valid criteria in accordance with the validity level category.

3.3. Validity Of ERIC Learning Devices (Educational Research on Integrated Combinatorial-Thinking)

The criteria for the validity of the devices that have been developed can be seen from the scores of the three validators. The results of the validation scores carried out by three validators of the learning device can be seen in Figure 2.

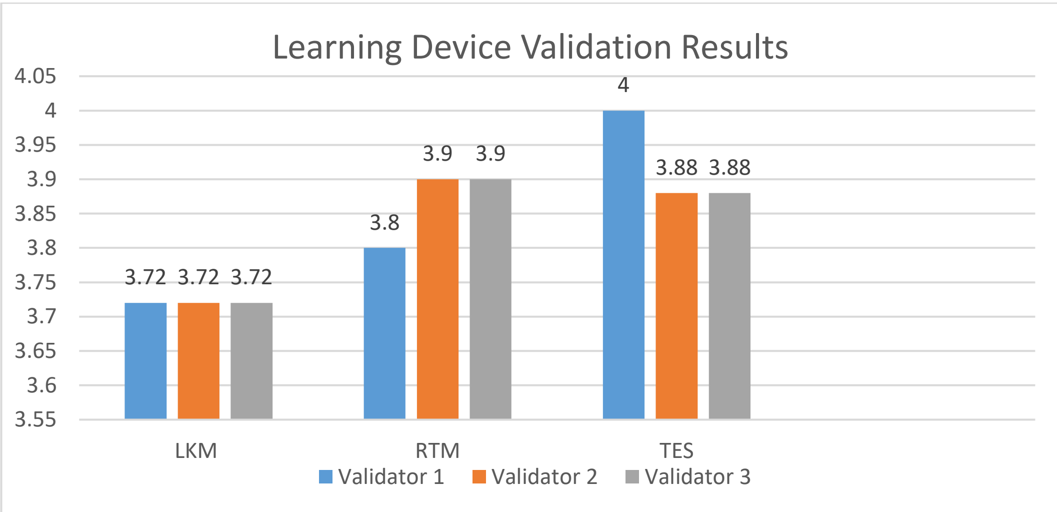

Figure 2.
Learning device validation results.

Based on the results of Figure 2, the results of student worksheet (LKM) validation from three validators are 3.72, 3.72, and 3.72. The results of RTM validation from three consecutive validators are 3.80, 3.90, and 3.90. The combinatorial thinking test validation results from the three validators were 4.00, 3.88, and 3.88, respectively. Based on the data analysis of the validation results, the validity coefficient ($\overline{V_a}$) is obtained for each product that has been developed and can be seen in the following Table 3.

Table 3.
Learning device validity coefficient.

No	Products	V_a	Criteria
1	student worksheet (LKM)	3,741	Valid
2	RTM	3,856	Valid
3	Combinatorial thinking ability test	3,938	Valid

Based on Table 3, it is obtained that the learning device has met the valid criteria. Based on the results of the validator's assessment, the validity of the learning tools can be used when implementing the ERIC learning model.

3.4. Validity of ERIC Learning Instrument (Educational Research on Integrated Combinatorial-Thinking)

The criteria for the validity of the ERIC learning instrument that has been developed can be seen from the scores of the three validators. The results of the validation scores carried out by three validators of the learning instrument can be seen in Figure 3.

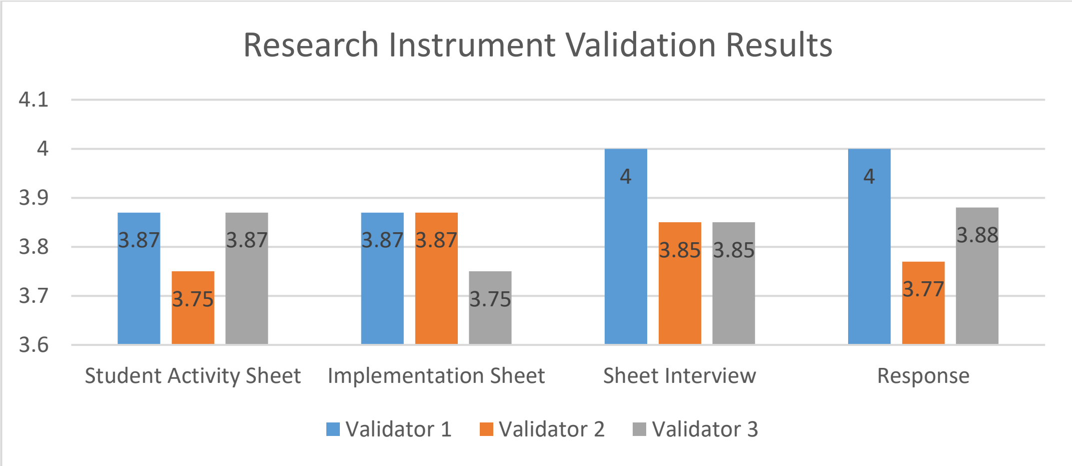

Figure 3.
Research instrument validation results.

Based on the results of Figure 3, the results of the validation of student activity sheets from three validators are 3.87, 3.75, and 3.87. The results of the validation of the implementation sheet from three validators in a row are 3.87, 3.87, and 3.75. The results of the validation of the interview sheet from three validators were 4.00, 3.85, and 3.85. The validation results of the three validators' response sheets were 4.00, 3.77, and 3.88. Based on the data analysis of the validation results, the validity coefficient ($\bar{V_a}$) was obtained for each product that has been developed, which can be seen in Table 4.

Table 4.
Validity coefficient of the research instrument.

No	Products	V_a	Criteria
1	Student Activity Sheet	3,834	Valid
2	implementation sheet	3,852	Valid
3	interview sheet	3,908	Valid
4	response sheet	3,897	Valid

Based on Table 4, it is obtained that the research instrument has met the valid criteria. Based on the assessment results of the three validators, the validity of the research instrument can be used when implementing the ERIC learning model.

3.5. Practicality of the ERIC Model

The criteria for the practicality of the ERIC learning model are determined from the scores on the model implementation observation sheet and the student activity observation sheet. Three observers made observations. The results of the observation of the implementation of the ERIC model can be seen in Table 5.

Table 5.
Percentage of Observation of Model Implementation.

No.	Activities	Observer			Average Value of Aspects
		O1	O2	O3	
1.	Syntax	3,75	3,75	3,75	3.75
2.	Social System	4	3,67	4	3.89
3.	Reaction and management principles	3,84	3,84	3,84	3.84
Total					11.48
Percentage					95.67%
Criteria					Very good

Based on Table 5, the percentage of learning model implementation is 95.67%. This means that implementing the ERIC learning model is a very good criterion.

Three observers also carried out practicality criteria for student activities. The results of observations of student activity on the implementation of the ERIC model can be seen in Table 6.

Table 6.
Percentage of Student Activity Observation Results.

No	Group	Rata-Rata (%)
1	Group 1	94,12
2	Group 2	92,64
3	Group 3	95,59
4	Group 4	97,05
Average		94,85
Criteria		Very Active

Based on Table 6, the average level of student activeness is 94.85% with very active criteria.

3.6. Effectiveness of the ERIC Model

The effectiveness of the ERIC model is determined from the scores obtained on the student response questionnaire and student combinatorial thinking test after implementing learning with the ERIC model. The student response questionnaire contains "Yes" or "NO" answers to statements given by researchers about student learning experiences using the ERIC learning model and its tools. The data from the student response questionnaire can be seen in Table 7.

Table 7.
Percentage of Student Response Questionnaire.

Number Statement	Percentage of Student Answers	
	YES (%)	NO (%)
1	100	0
2	100	0
3	85	15
4	100	0
5	100	0
6	90	10
7	100	0
8	100	0
9	100	0
10	95	5
11	100	0
12	100	0
13	100	0
14	100	0
15	95	5
16	95	5
17	100	0
18	100	0
19	90	10

Overall, the percentage of student answers can be seen in Figure 4.

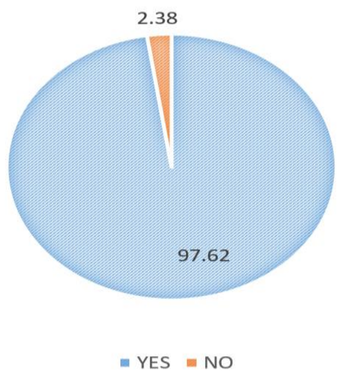

Figure 4.
Student Response to Learning.

Based on Figure 4, the percentage of student answers obtained was 97.6% of students who gave a positive response to learning using the ERIC model and its tools, so the results showed that the percentage value of student responses received a positive response.

The combinatorial thinking test was given after learning the ERIC model was completed. The test was given to PGRI Argopuro University Jember mathematics education students, as many as 20 students. The test was given to determine the combinatorial thinking ability of students. The combinatorial thinking ability of students was analyzed based on its indicators, namely identifying several problems, understanding problem patterns, applying mathematical patterns, mathematical proof, and considering several combinations of other problems. The combinatorial thinking test results can be seen in Table 8.

Table 8.
Combinatorial thinking ability based on indicators.

Number	Indicator	percentage
1	identify some problems	98.33
2	understand the pattern of the problem	95
3	applying mathematical patterns	91.66
4	mathematical proof	88.33
5	consider some combination of other problems	80

Table 8 shows that the indicator of identifying several problems is 98.33%; understanding the problem pattern is 95%; applying mathematical patterns is 91.66%; mathematical proof is 88.33%; and considering several other problem combinations is 80%.

4. Discussion

The development and validation of the ERIC (Educational Research on Integrated Combinatorial-Thinking) learning model showed significant progress in addressing gaps in students' combinatorial thinking skills. The integration of Problem-Based Learning (PBL) elements with combinatorial thinking indicators in the ERIC framework presents a pedagogical approach designed for mathematical problem-solving.

The results of this study highlighted the effectiveness of the ERIC learning model in training students' combinatorial thinking skills. This model successfully emphasizes the ability to identify problems, pattern recognition, mathematical applications, proof, and consideration of various combinations. These skills are critical in preparing students to deal with complex problem-solving scenarios in both academic and real-world contexts. Students showed high competence in identifying problems (98.33%) and understanding problem patterns (95%), which is in line with findings from Setianingsih, et al. [5] who emphasized that a structured and guided problem-solving approach can foster critical thinking.

The ERIC model was validated by experts with an average score of 3.737 (valid). The practicality assessment, with an implementation rate of 95.67% and student engagement of 94.85%, confirmed its feasibility in educational settings. This is in line with Blumenfeld, et al. [23] who state that models that encourage active student participation will result in higher engagement and better learning outcomes.

Positive feedback from students (97.6%) highlighted their acceptance of the ERIC model. The collaborative and discussion-oriented phases of the model, such as Collaboration and Discussion are instrumental in fostering a supportive learning environment. Johnson and Johnson [32] also highlighted that collaborative learning improves comprehension and retention, validating the ERIC model approach.

The ERIC model's emphasis on real-world problem-solving through combinatorial reasoning is aligned with 21st-century learning objectives. Students solve theoretical problems and develop skills that can be transferred to various professional and personal decision-making scenarios. Continued focus on pedagogy, curriculum, and skill acquisition is critical to developing 21st-century teaching skills [34].

Although PBL has been effective in fostering problem-solving and critical thinking skills [18] and can develop students' active learning abilities as well as active thinking and practical application of knowledge [35] its challenges, such as initial confusion and difficulties in task management [27] can be overcome in the ERIC model. The systematic integration of combinatorial thinking indicators provides clarity and structure, reducing the cognitive load on students while ensuring their active engagement.

5. Conclusion

The ERIC learning model is an innovative step in mathematics education, especially in fostering critical and combinatorial thinking skills. The ERIC learning model represents a significant advance in educational practice, combining the strengths of PBL with the specificities of combinatorial thinking. Its validation, practicality, and effectiveness underscore its potential to enhance critical thinking skills and prepare students for real-world challenges. Further refinement and broader implementation of the ERIC model will contribute to its evolution as an innovative educational cornerstone.

References

[1] T. O. Seng, *Problem based learning innovation: Using problem to power learning in 21th century*. Singapore: Thomson Learning, 2003.

[2] T. Mazidah, Dafik, and Slamin, "On the student's combinatorial thinking skills under the implementation of research based learning in solving resolving independent domination number of graphs," presented at the Journal of Physics: Conference Series, IOP Publishing Ltd,, 2021.

[3] L. Ulandari, Z. Amry, and S. Saragih, "Development of learning materials based on realistic mathematics education approach to improve students' mathematical problem-solving ability and self-efficacy," *International Electronic Journal of Mathematics Education,* vol. 14, no. 2, pp. 173-188, 2019. https://doi.org/10.29333/iejme/5721

[4] F. A. B. Asmara, S. Susilawati, and N. M. Sari, "Improving mathematical connection skills and self-efficacy through the 7E learning cycle model," *Jurnal Nasional Pendidikan Matematika,* vol. 5, no. 1, p. 160, 2021. https://doi.org/10.33603/jnpm.v5i1.3628

[5] R. Setianingsih, C. Sa'dijah, A. R. As'ari, and M. Muksar, "Investigating fifth-grade students' construction of mathematical knowledge through classroom discussion," *International Electronic Journal of Mathematics Education,* vol. 12, no. 3, pp. 383–396, 2017. https://doi.org/10.29333/iejme/619

[6] Y. F. Lay, "Logical thinking abilities among form 4 students in the interior division of Sabah, Malaysia," *Journal of Science and Mathematics,* vol. 32, no. 2, pp. 161–18, 2009.

[7] L. D. English, "Young children's combinatoric strategies," *Educational Studies in Mathematics,* vol. 22, no. 5, pp. 451–474, 1991. https://doi.org/10.1007/BF00367908

[8] G. Yuen, *Problem solving strategies students use when solving combinatorial problems*. The University of British Columbia. https://doi.org/10.14288/1.0070808, 2008.

[9] D. Rapanca, T. Wibowo, and M. Sapti, "The structure of students' combinatorial thinking in solving mathematical problems," *Jurnal Pendidikan Surya Edukasi,* vol. 6, no. 1, pp. 96–103, 2020. https://doi.org/10.37729/jpse.v6i1.6496

[10] J. Medová, K. O. Bulková, and S. Čeretková, "Relations between generalization, reasoning and combinatorial thinking in solving mathematical open-ended problems within mathematical contest," *Mathematics,* vol. 8, no. 12, pp. 1–20, 2020. https://doi.org/10.3390/math8122257

[11] B. J. Septory, Dafik, and I. M. Tirta, "The analysis of students' combinatorial thinking skills in solving r-dynamic vertex coloring under the implementation of problem-based learning," *Journal of Physics: Conference Series, Institute of Physics Publishing*, 2019. https://doi.org/10.1088/1742-6596/1211/1/012084

[12] M. Rezaie and Z. Gooya, "What do I mean by combinatorial thinking?," *Procedia - Social and Behavioral Sciences,* vol. 122, pp. 122–126, 2011. https://doi.org/10.1016/j.sbspro.2011.01.046

[13] S. E. Ammamiaritha and E. Surya, "Development of learning devices oriented problem-based learning to increase student's combinatorial thinking in mathematical problem-solving ability," presented at the 2nd Annual International Seminar on Transformative Education and Educational Leadership (AISTEEL 2017) Atlantis Press, 2017.

[14] C. Batanero, V. Navarro-Pelayo, and J. D. Godino, "Effect of the implicit combinatorial model on combinatorial reasoning in secondary school pupils," *Educational Studies in Mathematics,* vol. 32, no. 2, pp. 181-199, 1997. https://doi.org/10.1023/A:1002983604974

[15] L. D. English, *Combinatorics and the development of children's combinatorial reasoning. In Exploring Probability in School*. Springer-Verlag. https://doi.org/10.1007/0-387-24530-8_6, 2005.

[16] N. Salavatinejad, H. Alamolhodaei, and F. Radmehr, "Toward a model for students' combinatorial thinking," *Journal of Mathematical Behavior,* vol. 61, p. 100823, 2021. https://doi.org/10.1016/j.jmathb.2020.100823

[17] E. D. Putra, S. Slamin, A. I. Kristiana, and A. Suwito, "Development of combinatorial thinking ability questions for students," *International Journal of Current Science Research and Review,* vol. 7, no. 9, p. 58, 2024. https://doi.org/10.47191/ijcsrr/V7-i9-58

[18] R. Phungsuk, C. Viriyavejakul, and T. Ratanaolarn, "Development of a problem-based learning model via a virtual learning environment," *Kasetsart Journal of Social Sciences,* vol. 38, no. 3, pp. 297-306, 2017. https://doi.org/10.1016/j.kjss.2017.01.001

[19] E. H. Yew and K. Goh, "Problem-based learning: An overview of its process and impact on learning," *Health Professions Education,* vol. 2, no. 2, pp. 75-79, 2016. https://doi.org/10.1016/j.hpe.2016.01.004

[20] A. Magaji, "Promoting problem-solving skills among secondary science students through problem based learning," *International Journal of Instruction,* vol. 14, no. 4, pp. 549-566, 2021. https://doi.org/10.29333/iji.2021.14432a

[21] Y. I. Sari, D. H. Utomo, and I. K. Astina, "The effect of problem based learning on problem solving and scientific writing skills," *International Journal of Instruction,* vol. 14, no. 2, pp. 11-26, 2021. https://doi.org/10.29333/iji.2021.1422a

[22] A. S. Argaw, B. B. Haile, B. T. Ayalew, and S. G. Kuma, "The effect of problem based learning (PBL) instruction on students' motivation and problem solving skills of physics," *Eurasia Journal of Mathematics, Science and Technology Education,* vol. 13, no. 3, pp. 857-871, 2016. https://doi.org/10.12973/eurasia.2017.00647a

[23] P. C. Blumenfeld, E. Soloway, R. W. Marx, J. S. Krajcik, M. Guzdial, and A. Palincsar, "Motivating project-based learning: Sustaining the doing, supporting the learning," *Educational Psychologist,* vol. 26, no. 3-4, pp. 369-398, 1991. https://doi.org/10.1080/00461520.1991.9653139

[24] Y. Gülbahar and H. Tinmaz, "Implementing project-based learning and e-portfolio assessment in an undergraduate course," *Journal of Research on Technology in Education,* vol. 38, no. 3, pp. 309-327, 2006.

[25] R. W. Marx, P. C. Blumenfeld, J. S. Krajcik, and E. Soloway, "Enacting project-based science," *The Elementary School Journal,* vol. 97, no. 4, pp. 341-358, 1997.

[26] C. I. Lee and F. Y. Tsai, "Internet project-based learning environment: The effects of thinking styles on learning transfer," *Journal of Computer Assisted Learning,* vol. 20, no. 1, pp. 31-39, 2004. https://doi.org/10.1046/j.1365-2729.2004.00074.x

[27] L. N. Chin, "The power of problem-based learning (PBL) in the EFL classroom," *Polyglossia,* vol. 16, no. 2, pp. 41–48, 2009.

[28] W. R. Borg and J. P. Gall, *Educational research: An introduction*, 7th ed. Boston USA: Pearson, 2003.

[29] J. Piaget, *The psychology of the child*. United States: Basic Books, 1972.

[30] L. S. Vygotsky, *Mind in society: The development of higher psychological processes*. Cambridge: MA: Harvard University Press, 1978.

[31] J. H. Flavell, "Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry," *American Psychologist*, vol. 34, no. 10, p. 906, 1979. https://doi.org/10.1037/0003-066X.34.10.906
[32] D. W. Johnson and R. T. Johnson, *Learning together and alone: Cooperative, competitive, and individualistic learning*, 5th ed. Boston: Allyn and Bacon, 1999.
[33] R. Paul and L. Elder, *Critical thinking: Tools for taking charge of your professional and personal life*. Boston: Pearson, 2014.
[34] C. Martinez, "Developing 21st century teaching skills: A case study of teaching and learning through project-based curriculum," *Cogent Education*, vol. 9, no. 1, p. 2024936, 2022. https://doi.org/10.1080/2331186X.2021.2024936
[35] G. Xu, L. Zhao, and M. Zhou, "Effectiveness of problem-based learning combined with lecture based learning methodology in renal pathology education," *Cogent Education*, vol. 10, no. 1, p. 2172788, 2023. https://doi.org/10.1080/2331186X.2023.2172788