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Development of an Instrument to Measure Problem Solving and Numeracy Literacy Based on Ethnomathematics.

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ABSTRACT

Problem solving and numeracy literacy are essential competencies in 21st-century mathematics education, as they require students to understand, apply, and interpret mathematical concepts in real-world contexts. However, school assessments remain predominantly procedural and have not comprehensively measured these competencies. This study aimed to develop a contextual essay-based test instrument grounded in ethnomathematics to assess senior high school students' problem solving and numeracy literacy skills. This research employed a research and development (R&D) method, including needs analysis, test blueprint design, item development, expert validation, limited field testing, and item analysis using the Classical Test Theory approach supported by SPSS. The trial involved 28 twelfth-grade students of SMA Negeri 1 Ketapang. The results showed that the instrument demonstrated very high content validity (average 95.31%) and empirical validity, as student responses reflected the indicators of problem solving and numeracy literacy based on the analytic rubric. The reliability coefficients were very high, with Cronbach's Alpha values of 0.907 for problem solving and 0.918 for numeracy literacy. All items were categorized as having moderate difficulty levels and good to very good discrimination indices. The novelty of this study lies in the simultaneous integration of Polya's problem-solving stages and the PISA numeracy framework into an empirically validated assessment instrument based on local ethnomathematical contexts. This instrument provides a more contextual and authentic alternative for assessing higher-order thinking skills in mathematics.

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Introduction

Twenty-first century mathematics education requires students to possess higher-order thinking skills that go beyond procedural mastery. Rapid social, economic, and technological changes have positioned reasoning, problem solving, and data-based decision-making as essential competencies. Within the global competence framework, mathematical literacy is defined as the ability to formulate, employ, and interpret mathematics in various real-life contexts (OECD, 2019; OECD, 2023). Numeracy literacy extends beyond computational skills, encompassing the interpretation of quantitative information, modeling, argumentation, and reflection on obtained solutions (Stacey, 2015). The Programme for International Student Assessment (PISA) consistently identifies mathematical literacy as a key indicator of the quality of a country's education system. PISA 2022 highlights that many students across countries still struggle with contextual problems requiring complex reasoning (OECD, 2023). PISA tasks are designed to assess students' ability to connect mathematics with real-world situations rather than merely recall formulas, reinforcing the view that numeracy literacy is integrative and reasoning-oriented.

In Indonesia, analyses of mathematical literacy using international test designs indicate that students face difficulties in interpreting data-based information and relating it to contextual situations (Mahdiansyah & Rahmawati, 2014). This finding is supported by Sujadi et al. (2023), who reported that junior secondary students struggled with PISA-like tasks in the content domain of uncertainty and data. Similarly, Rohim & Rofiki (2024) found that most students were unable to provide logical mathematical justifications for their responses in numeracy-based AKM tasks. These results suggest that Indonesian students' numeracy literacy, particularly in reasoning and decision-making, requires further strengthening. Conceptually, numeracy literacy is closely related to problem solving. Polya (1973) emphasized that problem solving is central to mathematical activity, involving understanding the problem, devising a plan, carrying out the plan, and reflecting on the solution. From the perspective of mathematical competencies, problem solving integrates reasoning, representation, and communication skills (Niss & Højgaard, 2019). Therefore, numeracy literacy inherently involves problem-solving processes when students encounter non-routine contextual problems.

Empirical studies also confirm the relationship between numeracy literacy and problem solving. Alo (2025) found a significant correlation between numeracy literacy orientation and senior high school students' problem-solving ability. Baharuddin et al. (2025) reported that a problem-solving learning model positively influenced primary school students' literacy and numeracy skills. Andriani et al. (2025) similarly demonstrated that problem-solving ability in social arithmetic contexts is closely related to students' understanding of contextual situations. These findings reinforce that numeracy literacy and problem solving are inseparable in mathematics learning and assessment practices. Despite this, school assessments remain predominantly procedural and algorithmic, emphasizing final answers rather than students' thinking processes. Widana (2017) argued that higher-order thinking skills (HOTS) assessment requires instruments capable of measuring analysis, evaluation, and creation. However, many existing instruments do not comprehensively accommodate indicators of problem solving and numeracy literacy, resulting in suboptimal measurement of students' higher-order thinking skills.

Developing valid and reliable instruments is therefore a strategic step. Validity and reliability are fundamental prerequisites to ensure that instruments accurately measure intended constructs (Taherdoost, 2016). Faishol et al. (2025) demonstrated that systematically developed literacy and numeracy instruments can achieve high internal consistency. Munawarah et al. (2025) developed an ethnomathematics-based instrument to measure critical thinking and

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showed that clearly defined indicators reveal students' ability variations more authentically. Moreover, contextual factors significantly influence the quality of student responses. Bishop (1988), through the concept of mathematical enculturation, emphasized that mathematics is embedded in cultural practices. Ethnomathematics views mathematical activity as part of social and cultural life, and integrating cultural contexts into learning makes mathematics more meaningful and relevant for students (Sirate, 2012).

Previous studies have highlighted the effectiveness of ethnomathematics approaches in enhancing mathematical abilities. Astuti & Jana (2022) found that ethnomathematics-based worksheets improved students' mathematical representation skills. Muntazhimah et al. (2025) reported improvements in problem-solving ability through ethnomathematics-based e-worksheets. Fitri & Sari (2025) observed enhanced mathematical literacy using an ethnomathematics module aligned with the Pancasila Student Profile. Sam et al. (2025) also found that ethnomathematics-based transformation geometry textbooks effectively improved mathematical literacy. Isnaintri et al. (2024) developed a numeracy instrument incorporating local wisdom from Pandeglang and showed that cultural context deepened students' understanding of geometry problems. These findings indicate that ethnomathematics holds strong potential not only in instruction but also in assessment development.

However, comprehensive integration of numeracy literacy, problem solving, and ethnomathematics into a single empirically validated assessment instrument remains limited. Most Indonesian numeracy literacy studies focus on analyzing student performance in international assessments or AKM (Mahdiansyah & Rahmawati, 2014; Rohim & Rofiki, 2024), rather than developing new measurement tools grounded in students' characteristics and local cultural contexts. Research on problem solving often emphasizes instructional models rather than explicit instrument development mapping problem-solving indicators within a numeracy literacy framework (Baharuddin et al., 2025; Andriani et al., 2025). Likewise, ethnomathematics studies predominantly focus on teaching materials rather than constructing empirically validated assessment instruments (Astuti & Jana, 2022; Fitri & Sari, 2025; Muntazhimah et al., 2025; Sam et al., 2025).

Furthermore, few studies explicitly integrate Polya's problem-solving stages with PISA-based numeracy literacy indicators and translate them into culturally grounded test items analyzed comprehensively for validity, reliability, item difficulty, and discrimination power. Without technically validated instruments, the measurement of higher-order thinking skills risks inaccuracy and methodological weakness (Taherdoost, 2016). Accordingly, this study addresses three major research gaps: (1) conceptual integration of problem solving and numeracy literacy within a unified assessment framework; (2) integration of ethnomathematical contexts as the foundational basis for item construction rather than merely contextual illustrations; and (3) comprehensive empirical testing of instrument quality at the senior high school level. This study contributes theoretically by clarifying the relationship among constructs and methodologically by developing a standardized, contextual, and empirically validated assessment instrument.

Method

Research Design

This study employed a research and development (R&D) design aimed at producing a valid and reliable ethnomathematics-based test instrument to measure senior high school students' problem solving and numeracy literacy skills. The instrument development was conducted systematically through several stages: needs analysis, blueprint construction,

development of contextual test items, expert validation, limited field testing, and item characteristic analysis. This approach was selected to ensure that the resulting instrument met both content and empirical feasibility criteria prior to broader implementation.

Participants

The subjects of the limited field test were twelfth-grade students of SMA Negeri 1 Ketapang. The selection was based on the consideration that Grade XII students had completed statistics topics, particularly mean, median, and mode, and therefore possessed sufficient prior knowledge to respond to the developed items. This ensured a more accurate representation of item clarity and psychometric characteristics in measuring problem solving and numeracy literacy skills. In addition to student testing, content validation was conducted by two experienced senior high school mathematics teachers who teach statistics and have expertise in mathematics assessment. The involvement of expert validators aimed to evaluate the alignment of the items with the intended skill indicators, clarity of language, integration of ethnomathematical context, and appropriateness of cognitive level before the field testing stage.

Instrument

The primary instrument in this study was an ethnomathematics-based test designed to assess problem solving and numeracy literacy skills in the form of contextual essay questions. The instrument was developed based on a test blueprint aligned with mathematical problem-solving indicators and numeracy literacy indicators, integrated with the local socio-cultural context of Ketapang Regency. The tasks were designed to require students to understand contextual problems, determine appropriate solution strategies, perform necessary calculations, and interpret results for decision-making purposes. Each item was accompanied by an analytic scoring rubric. The problem-solving rubric was based on Polya's stages: understanding the problem, devising a plan, carrying out the plan, and reviewing and interpreting the solution. The numeracy literacy rubric included indicators of understanding quantitative information, applying mathematical concepts or procedures, interpreting and communicating results, and making data-based decisions. An example of task characteristics and assessment indicators is presented in Table 1.

Table 1. Task Description

Task	Task Characteristics
Tugas #1. Amplang Production in Kauman Village Students are provided with data on amplang production (kg) over 12 days and are asked to determine the statistical measure that best represents production conditions for planning the following week.	The task requires students to interpret quantitative information derived from local cultural data, determine an appropriate statistical measure, and justify their choice. The assessed problem-solving indicators include understanding the problem, devising a solution strategy, performing calculations, and interpreting results within a production context. Numeracy literacy indicators include interpreting data, applying statistical concepts, and making data-based decisions.
Tugas #2. Oil Palm Harvest Yield Students are given data on oil palm harvest yields from several plantation blocks and are asked to determine the mean, median, and mode, and to select the most appropriate measure as a reference for distribution planning.	The task measures students' ability to apply various statistical concepts accurately and compare results to select the most suitable measure for the problem context. Problem-solving indicators include strategy planning and solution evaluation, while numeracy literacy indicators involve applying mathematical procedures, interpreting results, and making decisions based on real plantation conditions.

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Tugas #3. Corn Harvest of Farmer Groups Students are provided with data on corn harvest yields from several farmers and are asked to determine the most representative statistical measure for setting a selling benchmark price.	The task requires students to connect statistical calculations with decision-making in a local socio-economic context. Problem-solving indicators include reviewing and interpreting solutions, while numeracy literacy indicators include communicating calculation results and explaining the implications of data-based decisions.

Data Collection Procedures

Data collection was conducted in several stages. The first stage involved content validation of the instrument by two senior high school mathematics teachers serving as expert validators. The validators were asked to evaluate the alignment of each test item with the intended skill indicators, clarity of language, integration of the ethnomathematical context, and appropriateness of the cognitive level. Feedback from the validators was used to revise and refine the instrument before proceeding to the field testing stage. The second stage was a limited field test administered to twelfth-grade students of SMA Negeri 1 Ketapang. The purpose of this trial was to obtain empirical data regarding item clarity, variation in student responses, and the feasibility of the items in measuring problem solving and numeracy literacy skills. All student responses were assessed using the previously developed analytic scoring rubrics.

Data Analysis

The data analysis aimed to determine the technical quality of the developed instrument through empirical validity, reliability, item difficulty, and discrimination index testing. The analysis employed the Classical Test Theory (CTT) approach supported by SPSS software. Interpretation criteria were established prior to analysis to ensure a systematic and measurable evaluation process. Since the instrument consisted of essay-type items, item validity was not examined using item–total correlation as commonly applied in objective tests. Instead, validity was evaluated in two stages: (1) content and construct validity assessed by expert validators, and (2) empirical validity based on students' responses in the field test. During the expert validation stage, the two validators assessed the alignment of items with problem solving and numeracy literacy indicators, the appropriateness of item construction, clarity of language, and the integration of ethnomathematical context. Their feedback was used to revise and improve the items prior to field testing. Content validity was calculated by determining the percentage of the obtained score relative to the maximum possible score using the following formula:

$$P = \frac{Obtained\ Score}{Maximum\ Score} \times 100\%$$

The resulting percentage was then interpreted according to the criteria presented in Table 2.

Table 2. Instrument Validity Criteria

Percentage	Category
81 – 100 %	Very Valid
61 – 80 %	Valid
41 – 60 %	Fairly Valid
≤ 40%	Not Valid

Subsequently, empirical validity was analyzed based on the extent to which each item elicited the targeted skill indicators, the variation of students' solution strategies, and the

consistency of scoring using the validated analytic rubric. An item was considered empirically valid if it generated responses representing the indicators of problem solving and numeracy literacy as specified in the test blueprint, demonstrated variation in students' ability levels, and could be scored consistently according to the agreed-upon rubric criteria. Thus, instrument validity was examined not only conceptually through expert judgment but also empirically through the characteristics of students' responses during the field test.

The results of the empirical validity analysis indicated that all items successfully elicited student responses aligned with the intended indicators. For each item, students demonstrated variations in understanding the problem, devising solution strategies, performing calculations, and interpreting results within the provided local cultural context. These variations enabled clear differentiation of students' ability levels through the analytic scoring rubric. Therefore, all items were declared empirically valid, as they adequately represented the constructs of problem solving and numeracy literacy as designed in the instrument blueprint. The criteria for interpreting reliability, item difficulty, and discrimination index are presented in Table 3.

Table 3. Criteria for Instrument Quality Testing

Aspect	Index	Criteria	Interpretation
Reliability	Cronbach's Alpha	≥ 0,90	Very High
		0,70 – 0,89	High
		0,50 – 0,69	Moderate
		< 0,50	Low
Item Difficulty	p = mean score/maximum score	p > 0,70	Easy
		0,30 ≤ p ≤ 0,70	Moderate
		p < 0,30	Difficult
Discrimination Index	D = (Mean upper group – Mean lower group) / maximum score	D ≥ 0,70	Very Good
		0,40 < D < 0,69	Good
		0,20 < D < 0,39	Fair
		< 0,20	Poor

Reliability testing was conducted using Cronbach's Alpha coefficient to determine the internal consistency among items within each construct. The analysis revealed that the problem-solving instrument obtained a Cronbach's Alpha value of 0.907, while the numeracy literacy instrument achieved a value of 0.918. Both coefficients fall within the very high reliability category. These results indicate that the items within each construct demonstrate excellent internal consistency and consistently measure the same underlying ability across respondents. Item difficulty analysis was performed by comparing the average score of each item to the maximum possible score. The calculated difficulty indices were 0.6339 for Item 1, 0.5446 for Item 2, and 0.5119 for Item 3. All values fall within the moderate difficulty category. A moderate difficulty level suggests that the items were neither too easy nor too difficult, thereby enabling proportional measurement of students' varying ability levels. Furthermore, the discrimination index was analyzed by comparing the mean scores of the upper and lower groups. The results showed discrimination indices of 0.7143 for Item 1, 0.5982 for Item 2, and 0.6964 for Item 3. The first item was categorized as very good, while the second and third items were categorized as good. These findings indicate that each item effectively differentiates between high- and low-ability students. Overall, the analysis demonstrates that the developed instrument meets strong technical quality criteria. All items were empirically valid based on response analysis and indicator alignment, demonstrated very high reliability, had moderate difficulty levels, and showed good to very good discrimination indices. Therefore, the instrument is suitable for use as a measure of ethnomathematics-based problem solving and numeracy literacy skills among senior high school students.

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Research Findings

The findings of this study were obtained through two main stages: expert validation and empirical field testing of the instrument with students. Data from both stages were analyzed quantitatively to objectively demonstrate the quality and feasibility of the developed instrument.

Table 4. Expert Validation Results

Validator	Maximum Score	Score Obtained	Percentage	Category
V1	64	62	96,88%	Very Valid
V2	64	60	93,75%	Very Valid
Average	64	61	95,31%	Very Valid

The instrument validation was conducted by two expert validators who evaluated four aspects: content relevance, construction, language clarity, and instrument specificity. The maximum possible total score was 64. The first validator assigned a score of 62 out of 64 (96.88%), while the second validator awarded 60 out of 64 (93.75%). The average validity percentage from both validators was 95.31%, which falls within the very valid category. These results indicate that the instrument met content and construct feasibility standards and was suitable for field testing after minor revisions based on the validators' suggestions.

Table 5. Instrument Reliability Results

Construct	Number of Items	N	Cronbach's Alpha	Category
Problem Solving	3	28	0,907	Very High
Numeracy Literacy	3	28	0,918	Very High

The empirical testing phase further examined the technical characteristics of each test item. Reliability analysis was conducted using Cronbach's Alpha coefficient. The results showed that the problem-solving instrument, consisting of three items, obtained an Alpha value of 0.907, while the numeracy literacy instrument, also comprising three items, achieved an Alpha value of 0.918. Both coefficients fall within the very high reliability category, indicating that the items within each construct demonstrate excellent internal consistency and stable measurement of the same underlying ability.

Table 6. Item Characteristics

Items	Difficulty (p)	Category	Discrimination Index (D)	Category
1	0,6339	Moderate	0,7143	Very Good
2	0,5446	Moderate	0,5982	Good
3	0,5119	Moderate	0,6964	Good

The item difficulty analysis indicated that all test items were classified within the moderate category. The difficulty indices, calculated by comparing the mean score obtained in the field test with the maximum possible score for each item, were 0.6339 for Item 1, 0.5446 for Item 2, and 0.5119 for Item 3. These findings demonstrate that each item possessed a balanced level of difficulty, being neither too easy nor too difficult for students. With difficulty indices in the moderate range, the test instrument is considered capable of optimally measuring students' abilities while providing sufficient information regarding their achievement in problem solving and numeracy literacy.

Furthermore, the discrimination index analysis revealed that all items demonstrated strong effectiveness in differentiating between high- and low-ability students. The discrimination indices were 0.7143 for Item 1, 0.5982 for Item 2, and 0.6964 for Item 3, all of

which fall within the very good and good categories. These results indicate that each item clearly distinguished the quality of student responses, as students with higher ability levels consistently achieved higher scores than those with lower ability levels. Overall, the results of the validity, reliability, item difficulty, and discrimination analyses indicate that the developed ethnomathematics-based problem solving and numeracy literacy test instrument meets established technical quality criteria. The instrument consistently, proportionally, and accurately measures students' abilities in alignment with the specified indicators. Therefore, it is deemed appropriate for use as a research instrument to assess senior high school students' mathematical problem solving and numeracy literacy skills within a local ethnomathematical context.

Discussion

The findings indicate that the developed instrument not only satisfies established technical criteria but also introduces an assessment approach distinct from conventional school practices. The expert validity score of 95.31% demonstrates strong conceptual and construct alignment between the test items and the intended indicators of problem solving and numeracy literacy. Furthermore, the Cronbach's Alpha coefficients of 0.907 for the problem-solving construct and 0.918 for numeracy literacy confirm very high internal consistency. From an instrument development perspective, reliability coefficients above 0.90 indicate strong measurement stability without suggesting excessive redundancy among items (Taherdoost, 2016; Faishol et al., 2025). Therefore, the instrument possesses a robust empirical foundation as a measure of senior high school students' mathematical abilities.

Beyond technical adequacy, the study contributes conceptually by integrating problem solving and numeracy literacy within a single assessment framework. Numeracy literacy in the PISA framework emphasizes the ability to formulate, employ, and interpret mathematics in real-world contexts (OECD, 2019; Stacey, 2015), whereas Polya (1973) highlights systematic thinking processes in understanding and resolving problems. By combining these perspectives, the instrument evaluates not only final numerical outcomes but also the reasoning processes underlying them. This integration aligns with Alo (2025), who reported a significant correlation between numeracy literacy orientation and students' problem-solving abilities.

Compared with conventional procedural assessments, the ethnomathematics-based instrument presents a different evaluation paradigm. Procedural tests primarily emphasize algorithmic accuracy and final answers, often overlooking students' interpretative and reflective capacities (Widana, 2017). Research suggests that students' difficulties in numeracy literacy tasks frequently stem not from computational errors but from challenges in contextual understanding and data interpretation (Mahdiansyah & Rahmawati, 2014; Rosyadi et al., 2024). The developed instrument explicitly requires students to justify their selection of statistical measures, interpret results meaningfully, and relate findings to local socio-economic contexts. Consequently, it is more sensitive in identifying higher-order thinking skills than traditional procedural assessments.

A primary strength of the instrument lies in its ethnomathematical foundation. Previous research has largely applied ethnomathematics to instructional materials such as worksheets, modules, and textbooks (Astuti & Jana, 2022; Fitri & Sari, 2025; Muntazhimah et al., 2025; Sam et al., 2025). This study extends its application to assessment design. Consistent with Bishop (1988) concept of mathematical enculturation, contextualized assessment more authentically reflects mathematical practices embedded within cultural life. In this instrument, culture functions not merely as narrative background but as the structural basis of quantitative problem situations grounded in local socio-economic realities. Pedagogically, the instrument

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carries significant implications. Unlike conventional assessments focused on procedures and final answers, the contextual essay format encourages students to articulate strategies, interpret data, and justify decisions. This aligns with Isnaintri et al. (2024), who found that integrating local wisdom into numeracy instruments enhances students' depth of understanding of contextual problems. By incorporating contexts such as local production, harvest outcomes, and community economic activities, students are prompted not only to compute but also to evaluate data-based decisions. This reflects global numeracy literacy objectives emphasizing informed decision-making grounded in quantitative information (OECD, 2021; OECD, 2023). Thus, the instrument measures not only academic performance but also cultivates reasoning skills relevant to real-life contexts.

Conceptually, this study contributes by integrating three key elements—problem solving, numeracy literacy, and ethnomathematics—within a unified, empirically validated assessment framework. Prior studies have generally examined these components separately, either through instructional models (Baharuddin et al., 2025; Andriani et al., 2025) or instructional materials (Sam et al., 2025). This research demonstrates that these elements can be systematically combined within a technically sound instrument. Accordingly, it contributes both practically, by offering an alternative assessment tool, and theoretically, by enriching discourse on contextual mathematics assessment development. Nevertheless, the instrument was tested on a limited number of respondents within a specific cultural context. Broader implementation across diverse cultural settings is necessary to examine the consistency of item characteristics in larger populations. Further analyses, such as construct validation or item response theory approaches, may strengthen the empirical evidence of the instrument's psychometric quality in future research. Overall, the findings suggest that the ethnomathematics-based problem solving and numeracy literacy instrument is not only technically feasible but also offers a more authentic, contextual, and competency-oriented assessment approach aligned with 21st-century educational demands. It may serve as a strategic alternative for teachers in assessing students' higher-order thinking skills in a more comprehensive and meaningful manner.

Conclusion

This study developed an ethnomathematics-based instrument to measure senior high school students' problem-solving and numeracy literacy skills that meets both conceptual and empirical feasibility criteria. Expert validation yielded an average validity percentage of 95.31%, categorized as very valid. Reliability testing produced Cronbach's Alpha coefficients of 0.907 for problem solving and 0.918 for numeracy literacy, both classified as very high. These findings indicate strong internal consistency and confirm the instrument's suitability as a measurement tool. The variation in students' scores across items demonstrates the instrument's ability to differentiate levels of ability and to elicit responses that comprehensively represent the stages of problem solving and the dimensions of numeracy literacy. The ethnomathematical context functions not merely as illustrative background but as an authentic problem source that promotes data interpretation and evidence-based decision-making. Accordingly, this instrument offers a more contextual and comprehensive alternative to conventional procedural mathematics assessments. Future research is recommended to implement the instrument with larger and more diverse populations across different cultural contexts to strengthen the generalizability of the findings and further examine its psychometric properties.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this study.

Authors' Contributions

H.S. contributed to the conceptualization of the study, instrument design, data collection, and preparation of the initial manuscript draft. D.R. contributed to instrument validation, data analysis, discussion of findings, and manuscript review and refinement. All authors participated in the revision process and approved the final version of the manuscript for publication. The overall contribution percentages to conceptualization, research implementation, manuscript preparation, and revision are as follows: H.S.: 60% and D.R.: 40%.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author, H.S., upon reasonable request.

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