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Design Thinking-Based Development of G-WAY (GeoGebra and Wayground) Learning Media in Kudus Local Cultural Context

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ABSTRACT

Critical thinking and mathematical multi-representation abilities among junior high school students in Kudus Regency, Indonesia, remain low to moderate, while earlier ethnomathematics-based media developed for this context relied on outdated technology and a largely linear design process with limited attention to user empathy. This design-and-development study integrates Design Thinking into the ADDIE framework—the main contribution of this research, enabling a design grounded in empirically documented user needs rather than curricular assumptions—to build G-WAY, a learning medium combining GeoGebra and the Wayground gamified-quiz platform, contextualized in the ethnomathematics of Menara Kudus. Only the first four Design Thinking stages (Empathize, Define, Ideate, and Prototype) are reported here; the Test stage, functional product development, and effectiveness evaluation lie outside this article's scope. Data came from a needs survey of 77 students from two schools, a survey of eight mathematics teachers from seven schools, and a silent-brainstorming session with 35 students. Empathize findings showed that 80.5% of students struggle with formulas, 68.8% of students identified abstract concepts and formulas as the factor most reducing their interest in mathematics, 44.2% were not used to giving reasons for their answers, and 37.7% found it difficult to turn a word problem into a picture or sketch, while 87.5% of teachers cited abstract concepts as the main obstacle and 62.5% reported that students use only the one representation taught by the teacher. These findings shaped the problem statements. Ideate-stage brainstorming yielded forty-two raw ideas narrowed to five priorities, elaborated at the Prototype stage into a prototype design with five components: a Problem-Based Learning syntax with a Menara Kudus problem orientation, GeoGebra visualization, a Wayground formative quiz, a Student Worksheet (LKPD) that supports multiple representations, and contextual problems based on Menara Kudus architecture. The prototype remains a design, not a functional product, pending expert validation and classroom trials. Each component traces back to empirical user data, positioning G-WAY as a culturally grounded, empathy-driven alternative to prior, technologically outdated ethnomathematics media, though its effectiveness still requires empirical testing at later stages.

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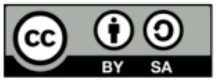

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1. INTRODUCTION

The Programme for International Student Assessment (PISA) 2022 ranked Indonesia 70th out of 81 participating countries in mathematics, with an average score of 366, far below the average of 472 recorded among member countries of the Organisation for Economic Co-operation and Development (OECD) [1]. At the district level, the 2023 Computer-Based National Assessment (Asesmen Nasional Berbasis Komputer/ANBK), released by the Education Standards, Curriculum, and Assessment Agency, reported that no more than fifteen percent of junior high school students in Kudus Regency reached the "proficient" level in numeracy literacy [2]. These figures indicate that low higher-order mathematical ability is not merely a macro-national phenomenon but a concrete reality experienced by students in Kudus.

Preliminary observations at several junior high schools in Kudus Regency show that geometry instruction is still dominated by conventional methods, makes minimal use of interactive digital media, and is rarely linked to local cultural context. This condition widens the gap between the twenty-first-century competency demands of the Kurikulum Merdeka—particularly its "Critical Reasoning" dimension—and actual classroom practice [3]. Critical thinking and mathematical multi-representation were chosen as the two target abilities in this study because both relate directly to the numeracy problem described above: to reach the "proficient" category on the ANBK, students must not only read and translate information across visual, numerical, and symbolic forms but also reason about and justify that information, and the two abilities are theoretically interdependent, since representing a problem in multiple ways is a prerequisite for effective critical thinking [4]. Geometric objects such as Menara Kudus are well suited to developing both abilities simultaneously, because interpreting its three-dimensional structure inherently demands multiple representations, while assessing its proportion, symmetry, and scale demands critical reasoning; however, prior research on ethnomathematics, GeoGebra, and augmented reality has generally targeted only one of these two abilities, so the simultaneous development of both within a single, culturally grounded medium remains rarely explored.

In response to this gap, this development study proposes a learning medium called G-WAY, an acronym for GeoGebra and Wayground, contextualized in the ethnomathematics of Kudus culture through the object of Menara Kudus. GeoGebra was chosen for its ability to display multiple mathematical representations simultaneously and dynamically, while Wayground was chosen as a a web-based gamifiedquiz platform that provides instant feedback, a leaderboard, and real-time learning-outcome reports without requiring additional software installationThe medium was developed using the ADDIE model enriched with a Design Thinking approach, because the conventional ADDIE model tends to be linear and does not explicitly prioritize empathy for the end user [5]. In contrast, Design Thinking places understanding of user needs at the very start of the design process [6].

The local cultural foundation of this medium is theoretically justified by the ethnomathematics perspective, which holds that mathematics grows from and alongside human life, and that every culture has its own ways of counting, measuring, and designing [7]. A previous effort to develop a Menara-Kudus-based medium used Adobe Flash

Professional CS6 [8], a technology that is now obsolete and does not support multi-representation interactivity, opening a clear opportunity for a more up-to-date, empathy-driven redesign. The specific novelty of G-WAY lies in combining three elements that previous studies generally treated separately or in pairs—a dynamic mathematics tool (GeoGebra), a gamified formativeassessment platform (Wayground), and a local ethnomathematics context (Menara Kudus)—into a single medium designed, through Design-Thinking-enriched ADDIE, to foster critical thinking and mathematical multi-representation simultaneously, rather than as separate outcomes.

This study aims to describe how Design Thinking was integrated into the ADDIE framework to identify student and teacher needs and develop an initial design for G-WAY. Accordingly, this article reports only the first four stages of Design Thinking—Empathize, Define, Ideate, and Prototype—drawing on field data from two perspectives at once: the student perspective as direct users, and the teacher perspective as learning facilitators. Combining both perspectives matters because the needs of a learning medium cannot be adequately formulated from only one side; the gap between what students need and what teachers can facilitate is itself a critical point that the medium's design must bridge. This study does not evaluate the effectiveness of G-WAY in improving students' critical thinking or mathematical multi-representation ability, since such an evaluation would require a Test stage and classroom trial that lie beyond the current scope of this study. The remainder of this article is organized as follows: Section 2 describes the research method; Section 3 reports and discusses the results of the Empathize, Define, Ideate, and Prototype stages together with the resulting G-WAY feature design; and Section 4 concludes the article.

2. METHOD

This study used a qualitative method with a Design Thinking approach. The Design Thinking framework was used as a structured approach to analyze a problem and formulate a contextually relevant solution [9]. Design Thinking is defined as a cognitive process, or way of thinking, embodied in the act of designing a thought process [10]. Design Thinking therefore offers a concrete way to solve complex problems that are well defined yet still hard to grasp. The five stages of the Stanford School Design Thinking model are shown below.



Figure 1. Design Thinking stages

The population of this study consisted of junior high school students and mathematics teachers implementing the Kurikulum Merdeka in Kudus Regency. The data-collection instrument was a needs questionnaire built in Google Forms, reviewed and validated by the thesis supervisor as an expert before distribution. The student questionnaire contained 24 items covering cognitive and affective aspects of learning mathematics, critical-thinking indicators, multi-representation indicators, use of GeoGebra and digital media, interest in local culture, and desired learning-media features. The teacher questionnaire contained 19 items covering teaching obstacles, teachers' assessment of students' multi-representation and critical-thinking ability, media and approaches previously used, experience integrating local Kudus culture, and needed features for a digital, ethnomathematics-based learning medium. The distribution of student and teacher respondents is presented in Table 1 and Table 2 below.

Table 1. Distribution of student respondents to the mathematics learning-needs questionnaire

School	n	%
SMP N 2 Kaliwungu	11	54.5
SMP N 5 Kudus	35	45.5
Total	77	100

Based on Table 1, student respondents came from two schools: SMP Negeri 2 Kaliwungu (54.5%) and SMP Negeri 5 Kudus (45.5%), for a total of 77 students from grades VII to IX. The distribution of teacher respondents is presented in Table 2 below.

Table 2. Distribution of teacher respondents to the initial teacher-needs questionnaire

Teaching Institution	n
SMP N 2 Kaliwungu	20
SMP N 5 Kudus	1
SMP N 3 Kudus	1
SMP N 4 Kudus	1
SMP Keluarga	1
SMP 3 Satu Atap Gebog	1
SMP N 1 Mejobo	1
Total	8

Teacher respondents had varying mathematics-teaching experience, ranging from 5–10 years to 20–25 years, and taught grades VII, VIII, and IX, providing a fairly representative picture of learning needs across junior high school levels. The research procedure followed a qualitative, Design-Thinking-based flow: (1) developing a blueprint and questionnaire instrument to map students' learning needs and teachers' readiness; (2) instrument validation by the expert supervisor; (3) online distribution of the questionnaire to students and teachers in schools across the Kudus region on a voluntary basis; and (4) analysis of questionnaire data to construct an empathy map, Point-of-View (POV) statements, and How-Might-We (HMW) questions as the basis for the Ideate and Prototype stages of the G-WAY medium's development.

3. RESULTS AND DISCUSSION

3.1 Results

Empathize Stage

At the Empathize stage, the researcher collected initial data from 77 students of SMP Negeri 2 Kaliwungu and SMP Negeri 5 Kudus, and 8 mathematics teachers from seven schools in the Kudus region, to understand learning obstacles, the state of students' critical-thinking and multi-representation ability, and expectations for a learning medium. Affectively, most students (42.9%) reported feeling neutral about mathematics, while 63.6% said they only sometimes felt confident when working on problems. The factor most commonly reported as reducing students' interest in mathematics was abstract, hard-to-understand concepts and formulas (68.8%), followed by a lack of confidence when working on problems in front of the class (45.5%).

From a critical-thinking perspective, item 11 of the questionnaire revealed that students' most common obstacles were being unaccustomed to giving reasons for their answers (44.2%), difficulty comparing and evaluating different solution strategies (39.0%), difficulty finding more than one way to solve a problem (28.6%), difficulty understanding real-world-context problems (26.0%), and not being accustomed to critically re-checking the correctness of answers (16.9%), as shown in Figure 2. This is consistent with the item on the habit of re-checking answers, where 27.3% of students admitted not knowing which part needed to be re-checked and 24.7% did not know how to detect errors in their own answers.

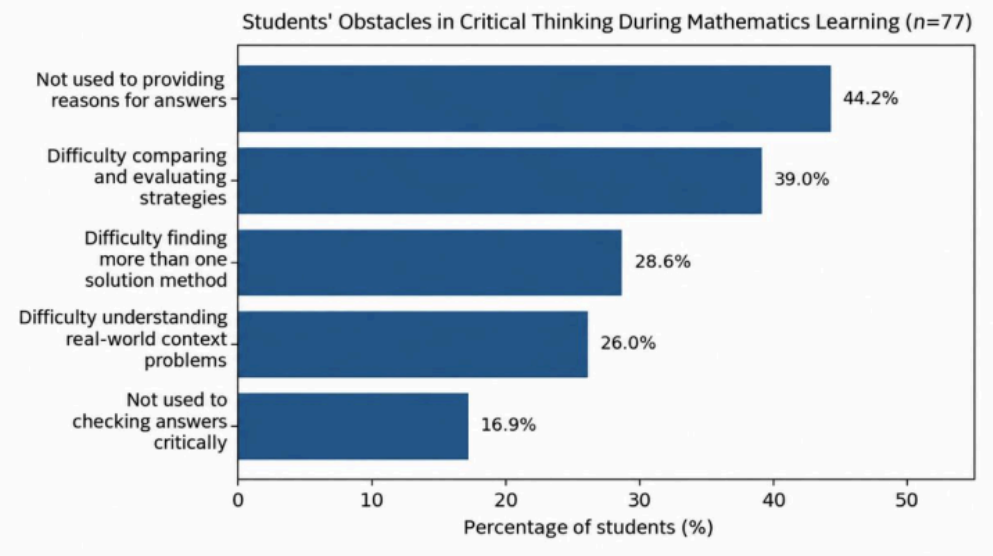

Figure 2. Students' obstacles in critical thinking when learning mathematics

This condition aligns with the finding that when facing a challenging problem, only 50.6% of students tried various approaches until finding a suitable solution, while 20.8% tended to try one approach and stop if it did not work. Likewise, students' difficulty with critical thinking is also reflected in a low habit of systematically analyzing problems: only 45.5% of students said they always understood a problem before working on it, while the rest did so conditionally or even rarely.

In terms of multi-representation, item 17 of the questionnaire showed that when presenting or explaining mathematics in different ways, 37.7% of students found it difficult

to turn a word problem into a picture or sketch, 35.1% found it difficult to explain a solution verbally or in writing in their own words, 32.5% were not yet accustomed to making a picture or sketch to solve a problem, and 27.3% found it difficult to present mathematical data in a table. Even so, 59.7% of students agreed that they could present a mathematical concept as a graph or diagram if given the opportunity, indicating multi-representation potential that could be further developed through an appropriate medium. The topics students considered most in need of multi-representation ability were Algebra (48.1%), Statistics (37.7%), Geometric Transformation (33.8%), and Systems of Linear Equations in Two Variables/SPLDV (32.5%).

Regarding local culture, 45.5% of students had never linked mathematics to local culture but were interested in trying, and 28.6% said they had done so a few times, for example through batik motifs, carvings, or mosque architecture. A total of 61.1% of students agreed or strongly agreed that mathematics learning should be linked to local culture, while 26.0% were neutral and 13.0% disagreed, preferring to focus on pure mathematics. In terms of digital-media use, 48.1% of students had used GeoGebra or a similar medium, while 32.5% had never used one at all. The learning media students considered most effective were still dominated by the whiteboard or direct explanation (76.6%), followed by YouTube (27.3%) and GeoGebra/Desmos (22.1%). The features students most expected in a learning medium were critical-thinking practice problems with step-by-step guidance (48.1%), space to try various representations such as tables, graphs, pictures, and verbal explanations (37.7%), interactive visualization of Kudus cultural geometric patterns (27.3%), context-based local animation or simulation (26.0%), dynamic exploration of graphs and geometric shapes (22.1%), and automatic feedback on answers or exploration (18.2%), as shown in Figure 3.

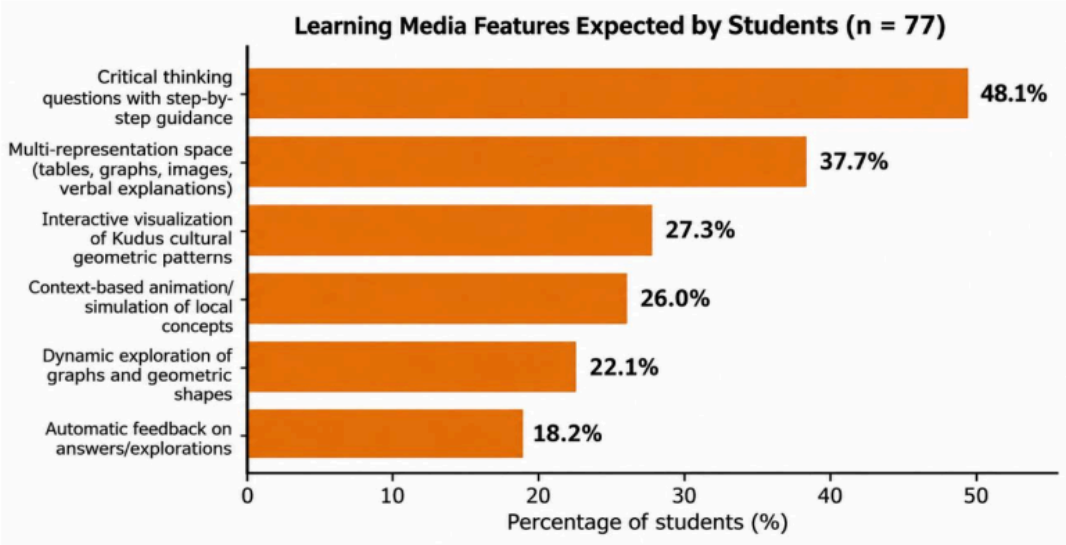

Figure 3. Learning-medium features expected by students

From the teachers' perspective, most felt enthusiastic and wanted to create an enjoyable and meaningful learning atmosphere when teaching mathematics. Nevertheless, 87.5% of teachers reported that students struggle to understand overly abstract concepts and

give up easily when facing difficult problems; 62.5% reported that students use only the one representation taught by the teacher, 50.0% highlighted low student learning motivation, 37.5% said not all students have access to digital media, and 25.0% complained about limited learning media and teaching aids, as shown in Figure 4.

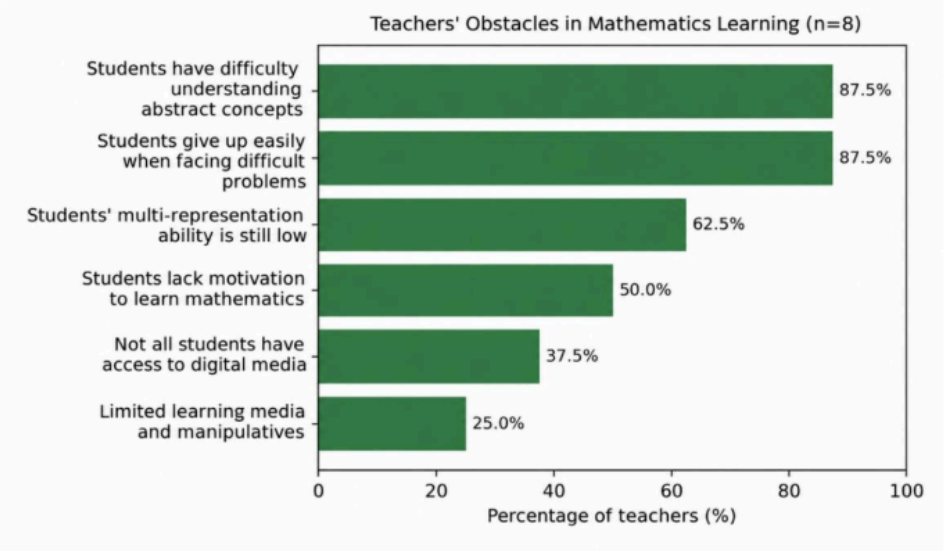

Figure 4. Teachers' obstacles in mathematics learning

Regarding students' multi-representation ability, 62.5% of teachers rated students as using only the one representation taught by the teacher (moderate category), 25.0% rated students as still struggling to use mathematical representations (low category), and only 12.5% rated most students as already able to use more than one representation (good category). A similar pattern appeared for students' critical-thinking ability: 50.0% of teachers rated it as still needing development (moderate), while 25.0% each rated students as already showing critical-thinking ability (good) or as still highly dependent on steps given by the teacher (low).

In terms of media use, all teachers (100%) had used teaching aids or real objects, 87.5% used instructional videos, 75.0% used educational games such as Quizizz or Kahoot, 62.5% used exploration-based worksheets, while use of GeoGebra (25.0%) and local-culture-based media (25.0%) remained relatively rare. Teachers also reported applying various approaches to support students' critical thinking and multi-representation, including inviting students to try different problem-solving approaches (87.5%), giving students the opportunity to explain and present their strategies (75.0%), and linking material to daily life or local culture (75.0%). Regarding integration of Kudus culture, 87.5% of teachers said they had integrated it before, though mostly occasionally and not yet systematically, with the most frequently raised elements being distinctive Kudus architecture such as towers, mosques, or traditional houses (37.5%), followed by distinctive Kudus batik or carving motifs (25.0%). A total of 75.0% of teachers considered the availability of an innovative learning medium based on Kudus ethnomathematics culture important to very important for junior high school mathematics learning.

Based on the student and teacher questionnaire results, the researcher constructed an empathy map, placing the results into four quadrants: says, thinks, feels, and does. For students, the empathy map shows that students say mathematics 'feels abstract and full of formulas,' think that they 'do not know the correct solution steps,' feel 'less confident when asked to explain an answer,' and tend to 'stop trying when one approach does not work.' For teachers, the empathy map shows that teachers say 'students give up easily and depend on the teacher's steps,' think that 'students' mathematical representation is still limited to one form,' feel that 'the available media and teaching aids are not yet sufficient,' and do 'try to link material to daily life, though not yet systematically linking it to local culture.'

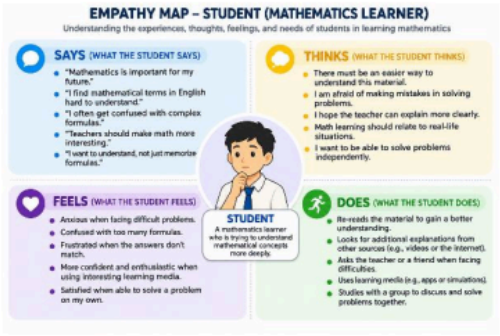

Figure 5. Student empathy map

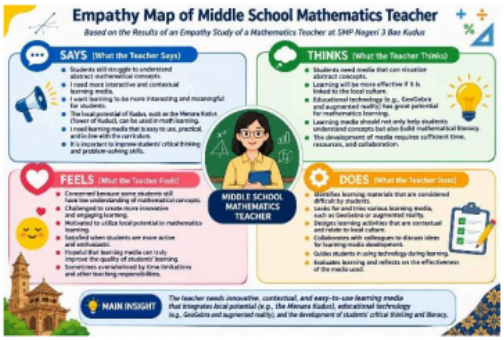

Figure 6. Teacher empathy map

Define Stage

At this stage, the researcher defined the core problem based on the Empathize analysis using the Point-of-View (POV) technique and the How-Might-We (HMW) framework [11], [12]. From the student perspective, the POV formulated was: "Junior high school students in Kudus need a way to understand abstract mathematical concepts, because they are not accustomed to giving reasons for their answers and find it difficult to present solutions in more than one form of representation, so they tend to give up when one solution approach does not work." From the teacher's perspective, the POV formulated was: "Mathematics teachers in Kudus need a learning medium that can build students' habits of critical thinking and multi-representation, because limited available media leaves students fixated on a single solution approach and not yet accustomed to systematically linking mathematics to local cultural context."

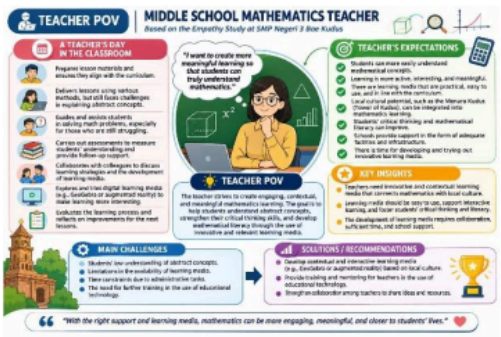

Figure 7. POV – junior high school students

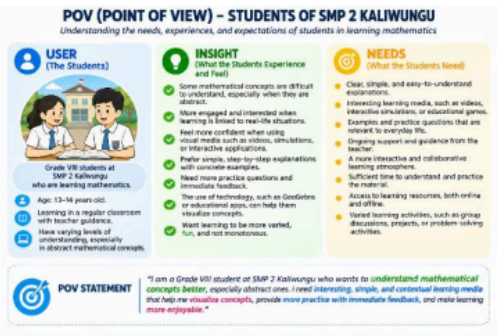

Figure 8. POV – junior high school mathematics teachers

Based on these two POVs, How-Might-We questions were formulated as idea triggers, including: (1) How might we help students build the habit of giving reasons for and critically evaluating solution strategies? (2) How might we provide space for students to try various representations—tables, graphs, pictures, and verbal explanations—in solving mathematical problems? (3) How might we link Algebra, Geometric Transformation, SPLDV, and Statistics material to Kudus cultural context close to students' daily lives? Moreover, (4) How might we provide instant, motivating feedback without reducing focus on conceptual understanding? These HMW statements guided the generation of solution ideas at the Ideate stage.

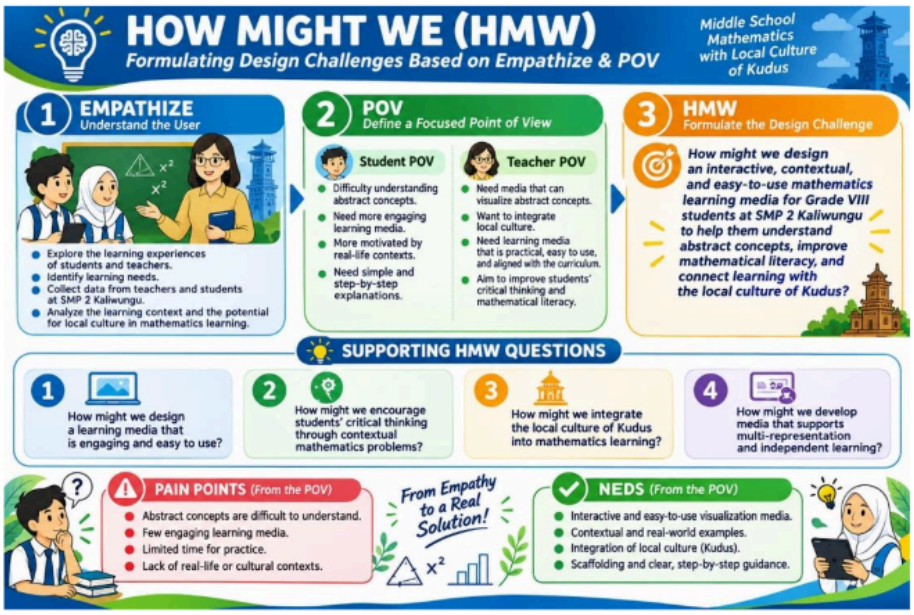

Figure 9. How-Might-We (HMW) statements

Ideate Stage

The Ideate stage was carried out through brainstorming to gather various solution ideas based on the Empathize and Define results [13]. A silent-brainstorming session involving 35 students generated fortytwo raw ideas, which were narrowed down to five priority ideas (Figures 10 and 11). This process produced an initial conclusion that a learning medium was needed that (1) provides critical-thinking practice problems with step-by-step guidance, (2) gives space to explore various mathematical representations, (3) visualizes concepts dynamically and interactively, (4) links material to local Kudus cultural context, and (5) provides motivating feedback for students. Based on the literature review, GeoGebra was chosen for its ability to visualize Algebra, Geometric Transformation, and Statistics concepts dynamically and multi-representationally, in line with findings that GeoGebra-assisted PBL can strengthen students' understanding of geometric concepts [14]. Meanwhile, Wayground—the result of Quizizz's 2025 rebranding—was chosen as a gamified quiz medium for formative assessment because of its instant-feedback, leaderboard, and real-time learning-outcome-reporting features, which have been shown to increase student motivation and engagement in mathematics learning [15], [16], [17].

The combination of these two media was named G-WAY (GeoGebra and Wayground), positioned not merely as two separate digital tools but as a single, mutually complementary learning medium: GeoGebra plays a role at the exploration and concept-construction stage through dynamic visualization and multi-representation, while Wayground plays a role at the reinforcement and formative-evaluation stage through gamified quizzes. To answer the third HMW, the ethnomathematics context of Kudus culture—particularly the architecture of Menara Kudus with its elements of symmetry, pattern, and geometric transformation—was integrated as the problem context in PBL, emphasizing the importance of bridging abstract mathematical concepts with cultural experiences close to students' lives [18], [19].

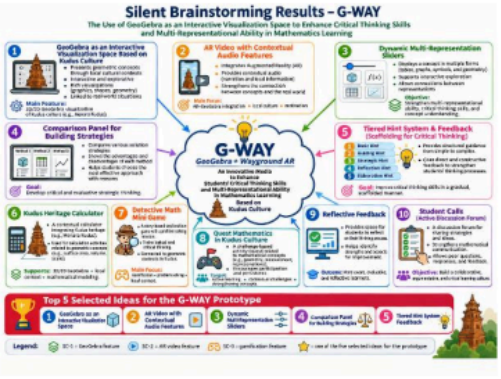

Figure 10. G-WAY mind map (1)

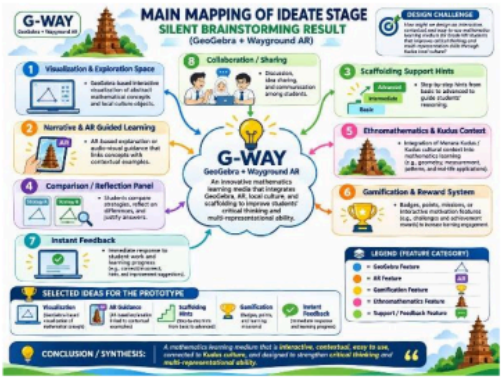

Figure 11. G-WAY mind map (2)

Prototype Stage

Based on the Ideate results, the researcher developed a prototype design of the G-WAY learning design integrated into the Problem-Based Learning (PBL) syntax. The prototype design covers five main components: (1) the PBL syntax was adapted by inserting a contextual problem orientation themed around Menara Kudus at the problem-orientation and investigation stages; (2) GeoGebra is used to visualize Algebra, Geometric Transformation, SPLDV, and Statistics material—the four topics that students identified (48.1%, 33.8%, 32.5%, and 37.7% respectively) as most needing multi-representation ability; (3) Wayground is used as a formative quiz at the closing stage of each session to provide instant feedback and monitor student achievement; (4) the Student Worksheet (LKPD) is designed to present problem-solving stages together with explicit space for students to write solutions in various representations—symbols, tables, graphs, and verbal explanations; and (5) contextual problems and illustrations are developed based on the geometric elements of Menara Kudus architecture, such as the curved symmetry of its gateway and the tower's carved patterns, to bridge abstract concepts with a cultural context familiar to students.

The prototype G-WAY lesson plan (RPP) was designed for two sessions of 2 × 40 minutes each, covering geometric-transformation material contextualized around Menara Kudus. The design was reviewed by the thesis supervisor as a content and instructional expert, and is accompanied by a practicality questionnaire instrument that will be used to

gather teacher and student responses on the ease of use and usefulness of the G-WAY medium at the trial stage.

Planned Test Stage

The Test stage has not yet been conducted; the following describes the planned procedure. The Test stage in this study is designed to be carried out through several steps: (1) validation of the media and learning materials by content and media experts; (2) validation of the critical-thinking and multi-representation assessment instruments in line with the indicators identified at the Empathize stage; (3) a limited trial of the PBL-based G-WAY learning design in the class serving as the research subject; (4) completion of a practicality questionnaire by teachers and students as a form of participant reflection; and (5) analysis of trial results to determine the practicality and potential effectiveness of the design before refinement in the next iteration. Given the iterative nature of Design Thinking, prototype testing is planned to be conducted more than once, with each iteration further evaluated based on teacher and student feedback. The results of expert validation and field trials will form the basis for refining the G-WAY design at the next stage of this development research.

3.2 Discussion

The results show that junior high school students' critical-thinking obstacles in Kudus lie mainly in the habit of giving reasons for answers and evaluating solution strategies, rather than solely in mastery of computational procedures. This finding aligns with the view that critical thinking in mathematics includes the ability to weigh, compare, and evaluate strategies, not merely execute algorithmic steps [20], [21], [22]. Students' low habit of critically re-checking answers also reinforces earlier findings that students tend to consider a task complete once they obtain an answer, without further evaluation [20].

From a multi-representation perspective, students' difficulty turning word problems into pictures or sketches and presenting data in tables shows that visual and tabular representation remain weaker points compared with symbolic representation, which is practiced more often in conventional learning. This gap is consistent with teachers' reports that most students use only the one representation taught by the teacher, indicating that representational flexibility has not yet been optimally built. This underscores the importance of media that explicitly provide space to practice various forms of representation, as offered by GeoGebra's dynamic visualization [14].

The finding that most students and teachers show a positive attitude toward linking mathematics with local culture strengthens the relevance of an ethnomathematics approach in this study's context. In line with the Ethno-RME framework, integrating cultural elements—in this case, Menara Kudus architecture—into mathematics learning can bridge abstract concepts with students' real experience, making learning more meaningful [23], [24]. Nevertheless, a portion of students (13.0%) and some teachers preferred to focus on pure mathematics, so the insertion of cultural context needs to be designed proportionally so as not to distract from the mathematical learning objectives themselves.

Unlike previous studies that generally positioned GeoGebra and quiz-based gamification media as two standalone interventions [14], [16], [17], this study proposes a G-WAY design that positions both as a single learning cycle: GeoGebra for exploration and

multi-representation concept construction, and Wayground for reinforcing critical thinking through instant formative feedback. This approach extends previous findings on the effectiveness of Quizizz/Wayground-based gamification in increasing student motivation and engagement [17], [25] by positioning it as part of a broader, human-centered learning design rather than merely an additional evaluation tool.

From a theoretical perspective, applying Design Thinking to design the G-WAY medium contributes a development process grounded in the actual needs of students and teachers, rather than the researcher's assumptions alone. Through the empathize, define, and ideate stages, the identified problems—difficulty with critical thinking, limited multi-representation, and minimal integration of local culture—directly became the basis for formulating prototype components at the next stage. This is in line with the view that Design Thinking is effective for designing mathematics learning media that are responsive to user needs [13], [26]. This study also supports the finding that technology-assisted PBL has a greater effect than PBL implemented without media support [27], [28], while extending it by adding ethnomathematics and gamification dimensions that have rarely been examined together at the junior high school level.

This study has several limitations that should be noted. First, the Test stage has not yet produced quantitative effectiveness data, as the study is still at the needs-analysis and prototype-formulation stage; field-trial results will be the focus of the next stage of this development research. Second, the successful implementation of G-WAY depends heavily on students' internet access and digital-device availability, given that 37.5% of teachers reported that not all students have access to digital media. Third, the insertion of local cultural context must continue to be evaluated so that it functions as a bridge to conceptual understanding rather than merely irrelevant decoration [29], [30]. Accordingly, infrastructure readiness and teachers' digital competence are important considerations that must be included in the further development and implementation of the G-WAY medium.

4. CONCLUSION

This study explored the mathematics-learning needs of junior high school students and teachers in the Kudus region through a Design Thinking approach to formulate a Problem-Based Learning design integrated with the G-WAY medium (GeoGebra and Wayground) based on Menara Kudus ethnomathematics. At the Empathize and Define stages, it was found that students' main obstacle in critical thinking lies in the habit of giving reasons for and evaluating solution strategies. In contrast, their multi-representation obstacle lies in difficulty turning problems into visual and tabular forms. Teachers also reported limited media and students' low habit of using more than one form of representation. Based on these findings, the Ideate and Prototype stages produced a G-WAY design combining GeoGebra for dynamic visualization and multi-representation of Algebra, Geometric Transformation, SPLDV, and Statistics concepts, with Wayground as a gamified quiz medium for reinforcing critical thinking through formative feedback, and the ethnomathematics context of Menara Kudus architecture as a bridge between mathematical concepts and students' cultural experience.

This study has implications for the development of Design-Thinking-based mathematics learning at the junior high school level. For teachers, these needs-analysis results can serve as a reference for designing learning that gives students more room to practice giving reasons, comparing strategies, and presenting concepts in various representations. For future researchers, the resulting G-WAY prototype design can be further developed through expert validity testing, field trials, and quantitative measurement of its effectiveness on students' critical thinking and multi-representation ability. For students, this problem-based learning approach, combined with dynamic visualization, gamification, and local cultural context, is expected to encourage active engagement and build confidence in solving mathematical problems critically and with multiple representations.

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