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Development of Interactive E-Module Based on Van Hiele Learning with Deep Learning Approach Assisted by GeoGebra 3D Augmented Reality to Stimulate Vocational High School Students' Spatial Literacy

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ABSTRACT

Spatial literacy is a crucial 21st-century competency supporting STEM learning; however, Indonesian students' achievement in space and shape content remains low (PISA 2022 score: 366). This research aims to develop an interactive e-module based on Van Hiele theory with a deep learning approach assisted by GeoGebra 3D Augmented Reality (AR) to enhance vocational high school students' spatial literacy. This study employed Research and Development (R&D) with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). The research subjects consisted of 32 twelfth-grade students at SMK Muhammadiyah Purworejo for the limited trial and 64 students (32 from SMK TKM Purworejo and 32 from SMK YPP Purworejo) for the field trial in the 2025/2026 academic year. Data collection techniques included interviews, expert validation questionnaires (material and media), teacher and student response questionnaires, and spatial literacy tests (pretest and posttest) based on visualization, reasoning, and spatial communication indicators. Data analysis used validation and practicality percentage, N-Gain test, paired sample t-test, and effect size (Cohen's d). The results showed the module was feasible for use as it met valid, practical, and effective criteria: (1) the e-module was declared very valid (86.25%); (2) very practical based on teacher responses (89.2% in limited trial, 92.1% in field trial) and student responses (84.6% in limited trial, 89.7% in field trial); (3) effective in improving spatial literacy with N-Gain of 0.68 (moderate category) in the limited trial and 0.65 (moderate category) in the field trial, paired sample t-test showed significant differences ($p < 0.05$) in both trials, and effect size of 1.12 (large category) in the limited trial and 1.04 (large category) in the field trial. This research contributes to developing technology-based geometry learning media in vocational education through the integration of Van Hiele syntax, deep learning approach, and GeoGebra 3D AR in one interactive e-module proven valid, practical, and effective.

Keywords: Spatial Literacy, Van Hiele, Geo Gebra 3D AR, Deep Learning, Interactive E-Module

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INTRODUCTION

Twenty-first-century education demands students possess critical thinking, creative, collaborative, communicative, digital literacy, numeracy, and adaptability skills to global developments (Hansen, 2020; Indarta et al., 2021). One crucial literacy supporting 21st-century competencies is mathematical literacy, encompassing thinking abilities, conceptual understanding, procedural use, and critical problem-solving in real contexts (OECD, 2021). Mathematical literacy is divided into three main competencies: spatial literacy, numeracy, and

quantitative literacy (Lange, 2003; OECD, 2023). Among these, spatial literacy is highly relevant as it plays a role in various modern professions such as architecture, engineering, arts, and medicine (Bednarz & Kemp, 2011). Recent research indicates that the higher students' Van Hiele thinking levels, the higher their spatial literacy in solving geometry problems.

Research on students' spatial literacy based on Van Hiele thinking levels shows that overall, the higher a person's Van Hiele thinking level, the higher their spatial literacy in solving geometry problems. This finding confirms that developing Van Hiele thinking levels is an effective strategy for improving students' spatial literacy. This aligns with Jufri et al.'s (2026) findings that students' spatial literacy varies according to their thinking levels; students at level 0 (visualization) have fairly good visualization skills but remain weak in reasoning and communication, students at level 1 (analysis) demonstrate good spatial literacy in visualization and reasoning, while students at level 2 (informal deduction) show strong spatial literacy across all indicators. Recent work on geometric reasoning further underscores the value of explicitly supporting learners as they progress across levels of geometric thought, rather than expecting abstract deduction to emerge without structured experiences (Arnal-Bailera & Manero, 2024; Asna et al., 2021).

Nirwana's research (2022) also revealed that students with high spatial intelligence are at the informal deduction thinking level (level 3), students with moderate spatial intelligence are at the analysis level (level 2), while students with low spatial intelligence are at the visualization level (level 1). Van Hiele's theory states that geometry learning must progress through five hierarchical thinking levels: visualization, analysis, informal deduction, formal deduction, and rigor. This theory emphasizes that students must pass through each level sequentially, and understanding at the previous level serves as a prerequisite for the next level. Van Hiele (1986) himself acknowledged that his geometric thinking levels are rooted in Piaget and Inhelder's spatial thinking stages, yet Van Hiele emphasized the importance of the teacher's role in the instructional process to develop students' spatial thinking. Therefore, geometry learning needs to be designed progressively according to Van Hiele thinking levels to optimize the development of students' spatial literacy. Moore-Russo et al. (2013) stated that spatial literacy has three main domains: visualization, reasoning, and communication.

In mathematics learning, spatial literacy is especially needed in geometry. Mas'udah et al. (2021) emphasized that geometry learning demands understanding, representation, communication, and reasoning. However, PISA study results show Indonesia's achievement in space and shape content remains low, with scores of 383 in 2016 and 366 in 2022, far below the OECD average (OECD, 2016; OECD, 2023). Interview results with teachers at SMK Muhammadiyah Purworejo also indicated that students experience "visual deadlock" when asked to imagine intersecting lines or relationships between penetrating planes. Learning remains conventional, teacher-centered, and limited to static images on whiteboards or textbooks. Lusyana and Setyaningrum's research (2018) showed that Van Hiele theory-based mathematics learning materials for vocational schools oriented toward spatial reasoning proved practical and effective, with students' spatial reasoning ability mastery percentage reaching 82%. Research on spatial abilities has been conducted more at the junior and senior high school levels, while at the vocational school level it remains limited. The developed learning materials consisted of Lesson Plans and Student Worksheets using the ADDIE development model, with spatial reasoning ability mastery reaching 82% after using these materials. These materials support students' reasoning abilities by providing illustrations and Cartesian planes to facilitate spatial thinking. Vocational school students require adequate spatial abilities because many vocational competencies relate to visualization and spatial reasoning, such as in engineering, architecture, and design. Suprapto et al.'s research (2021) showed that developing GeoGebra-based tutorial materials proved effective in improving vocational school students' mathematical spatial abilities, with validity percentage of 90.13%, practicality of 83.24%, and student learning mastery reaching 82.22%. However, Handayani (2025) found that vocational school students' spatial abilities vary according to their Van Hiele geometric thinking levels, and research on spatial abilities at the vocational school level remains limited compared to junior and senior high school levels. Researchers have developed a GeoGebra-supported learning trajectory to

foster students' spatial abilities through guided exploration of geometric concepts (Meirida et al., 2021). GeoGebra-based tutorial materials have also been reported as a potential support for vocational students' spatial mathematics abilities (Suprapto et al., 2021). Other studies demonstrate the potential of web-based worksheets and augmented reality resources when they are integrated with purposeful learning activities (Muchlis et al., 2021; Fitrianingsih et al., 2023). In addition, technology-supported design activities may provide opportunities to develop spatial ability (Dilling & Vogler, 2021).

A systematic review reported that augmented reality has potential to support the development of spatial intelligence in STEM learning, including mathematics (del Cerro Velázquez & Morales Méndez, 2021). A meta-analysis of augmented reality research in education also found learning benefits, while emphasizing the importance of examining instructional context and implementation (Chang et al., 2022). Research on augmented reality in mathematics further indicates that its effectiveness depends on how the technology is integrated into teaching and learning activities (Koparan et al., 2023; Yang et al., 2026).

Interactive e-modules have become one solution. E-modules are electronic teaching materials systematically arranged, containing materials, methods, and evaluation (Sidiq & Najuah, 2020). To be effective, e-modules need to be structured with appropriate learning models. The Van Hiele learning model is relevant because it focuses on the gradual development of geometric thinking (visualization, analysis, informal deduction) and has been proven to improve students' spatial abilities (Dimla & Soriano, 2019). Additionally, the deep learning approach in the Merdeka Curriculum emphasizes meaningful, in-depth, and enjoyable learning (Kemendikdasmen, 2025). From a technological perspective, GeoGebra 3D Augmented Reality provides great opportunities to visualize geometric objects interactively and realistically (Cheong et al., 2024; Gusteti et al., 2025).

Sugandi, Bernard, and Sofyan's research (2026) showed that GeoGebra and AR-assisted geometry learning significantly improved geometry competence, attitudes toward geometry, and 3D geometric thinking skills across all dimensions. Other research also shows that AR applications such as GeoGebra AR and 3D AR Escape Room have proven effective in supporting visualization of geometric concepts and connecting theory with real-world contexts. The use of AR in geometry learning generally has been proven to improve spatial abilities, conceptual understanding, and student engagement and motivation in learning. These findings are reinforced by del Cerro Velázquez and Morales Méndez (2021) who stated that GeoGebra 3D integration with AR improves spatial intelligence and optimizes volumetric geometry learning processes.

This research fills the gap from previous studies that still focused on using AR or Van Hiele separately. The novelty of this research is the integration of Van Hiele syntax, deep learning approach, and GeoGebra 3D AR in one interactive e-module to stimulate vocational school students' spatial literacy.

Based on the aforementioned background and identified gaps, this research aims to address the following research questions: (1) How is the validity of the interactive e-module based on Van Hiele learning with a deep learning approach assisted by GeoGebra 3D Augmented Reality developed to stimulate vocational high school students' spatial literacy? (2) How is the practicality of the interactive e-module based on Van Hiele learning with a deep learning approach assisted by GeoGebra 3D Augmented Reality developed to stimulate vocational high school students' spatial literacy?, and (3) How is the effectiveness of the interactive e-module based on Van Hiele learning with a deep learning approach assisted by GeoGebra 3D Augmented Reality in improving vocational high school students' spatial literacy?

METHOD

This research employed Research and Development (R&D) with the ADDIE development model (Analysis, Design, Development, Implementation, Evaluation) because it has a systematic and flexible flow (Branch, 2009). The research procedure included five stages: (1) analysis stage, identifying needs through observation, teacher interviews, and curriculum

review; (2) design stage, developing material concepts, media, and e-module components; (3) development stage, creating interactive e-modules and validation by material and media experts; (4) implementation stage, limited trials and field trials with iterative cycles; (5) evaluation stage, assessing validity, practicality, and effectiveness.

The research was conducted at three vocational high schools in Purworejo, Central Java, in the 2025/2026 academic year. The limited trial subjects were 32 twelfth-grade students at SMK Muhammadiyah Purworejo. The field trial subjects were 64 students from two vocational high schools: 32 students from SMK TKM Purworejo and 32 students from SMK YPP Purworejo. Data collection techniques included: (1) questionnaires for expert validation (material and media) as well as teacher and student responses; (2) interviews to explore learning obstacles; (3) tests, namely pretest and posttest spatial literacy (essay questions based on visualization, reasoning, and spatial communication indicators). Instrument validity was conducted using expert judgment based on spatial literacy indicators. Instrument reliability was analyzed using Cronbach's Alpha coefficient with a value greater than 0.70.

The implementation stage was conducted in two phases: limited trial and field trial. Each phase employed an iterative cycle procedure, where practicality and effectiveness were measured simultaneously in two cycles on the same subjects. In Cycle 1, the e-module was implemented, and data on practicality and effectiveness were collected. Based on observations, teacher interviews, and analysis of student results, revisions were made to address identified weaknesses. In Cycle 2, the revised e-module was re-implemented with the same subjects to verify that the revisions truly addressed the identified problems and improved the product's quality. This procedure ensures that each revision is empirically validated before proceeding to the next phase, unlike conventional R&D procedures where revisions are made without re-testing their impact. The iterative cycle also ensures that the final product aligns with the actual needs and characteristics of the target users, as revisions are based on direct feedback from the same subjects who experienced the initial product. The limited trial was conducted first to test the initial product with a smaller group, followed by revisions and a second cycle with the same group. After the limited trial produced a refined e-module (Version 3.0), the field trial was conducted with a larger and more diverse group from two different schools, following the same two-cycle procedure to ensure the product's practicality and effectiveness across broader contexts.

Data analysis techniques included validity analysis using the validation score percentage formula (Sugiyono, 2016) with criteria very valid (80-100%), valid (60-80%), fairly valid (40-60%), less valid (20-40%), and invalid (0-20%). Practicality analysis used response questionnaire percentage with criteria very practical (80-100%), practical (60-80%), fairly practical (40-60%), less practical (20-40%), and impractical (0-20%). Effectiveness analysis used N-Gain score (Hake, 1999) with categories high ($g>0.7$), moderate ($0.3<g\leq0.7$), low ($g\leq0.3$); paired sample t-test with normality tested first using Shapiro-Wilk; and Cohen's d effect size with criteria $d<0.20$ for small, $0.20\leq d<0.80$ for moderate, and $d\geq0.80$ for large.

RESULT AND DISCUSSION

Needs Analysis for Media Development

The needs analysis was conducted through learning observations, interviews with mathematics teachers, and review of student characteristics in mathematics learning, especially on three-dimensional geometry material at SMK Muhammadiyah Purworejo. The needs analysis activities were conducted considering that three-dimensional geometry material is a geometry topic with a fairly high level of abstraction. Unlike arithmetic material which involves more calculation operations, three-dimensional geometry material requires students to understand three-dimensional objects that cannot be fully observed through two-dimensional images on books or whiteboards. Therefore, the success of learning three-dimensional geometry material is greatly influenced by students' ability to understand, process, visualize, interpret, and represent spatial information.

Based on learning observations, it was found that mathematics learning processes are still dominated by lecture methods, textbook use, and conventional practice questions. Teachers

explain material using static images in books and on whiteboards. Meanwhile, learning media that can display three-dimensional objects interactively remain very limited. These conditions cause students to receive information passively rather than independently exploring geometry concepts.

Interview results with teachers also showed that students often experience difficulties in learning three-dimensional geometry. These difficulties arise not only when working on problems but also when understanding basic concepts related to shapes, positions, directions, relationships between geometric elements, and object representations in space. Many students can memorize formulas but do not yet understand the underlying geometric concepts. This indicates that the current learning process has not fully developed students' spatial literacy abilities. The needs analysis focused on four main aspects of spatial literacy: spatial visualization, spatial orientation, spatial relations, and spatial representation.

Product Development

The interactive e-module was developed using Flip PDF Professional application and integrates GeoGebra 3D AR. Van Hiele syntax (visualization, analysis, informal deduction) was translated into three learning phases: (a) introduction to 3D objects through AR, (b) analysis of properties and relationships between spatial elements, (c) drawing logical conclusions and solving contextual problems. The deep learning approach was implemented through independent exploration activities, small projects, and reflection.

The integration of Van Hiele syntax, deep learning approach, and GeoGebra 3D AR represents a novel contribution to geometry learning media. Unlike previous studies that used AR or Van Hiele separately (Arifin et al., 2020; Dimla & Soriano, 2019), this e-module combines these elements synergistically. The three learning phases correspond to Van Hiele's hierarchical levels, ensuring students progress systematically from concrete exploration to abstract reasoning. The AR component addresses the fundamental challenge of visualizing three-dimensional objects, while the deep learning approach encourages meaningful engagement through exploration, projects, and reflection. This integration is expected to provide a more comprehensive learning experience than conventional methods or single-component interventions. The resulting e-module product can be accessed online at: https://online.fliphtml5.com/Geometri1/ntnh/, containing the complete digital version along with integrated GeoGebra 3D AR simulations as used in this research trial stage.

Validity Results and Discussion

Validation results by two material experts and two media experts are presented in Table 1.

Table 1. Expert Validation Results of Interactive E-Module

Validation Aspect	Average Score	Percentage	Criteria
Content Feasibility (Material)	42.5/50	85%	Very Valid
Presentation Feasibility (Van Hiele Model)	44/50	88%	Very Valid
Language Feasibility	41/50	82%	Very Valid
Media Feasibility (GeoGebra 3D AR)	45/50	90%	Very Valid
Total Average	172.5/200	86.25%	Very Valid

Based on Table 1, the e-module was declared very valid with an average percentage of 86.25%, thus feasible for trial. The media feasibility aspect (GeoGebra 3D AR) obtained the highest percentage (90%), while the language feasibility aspect obtained the lowest percentage (82%) although still in the very valid category.

Limited Trial

The limited trial was conducted with a small group consisting of 32 students and 1 mathematics teacher**.** In this phase, practicality and effectiveness were measured simultaneously in two iterative cycles on the same subjects.

Practicality Results (Cycle 1)

In the first cycle, the GeoGebra 3D AR e-module was tested. Practicality questionnaires were completed by the teacher and students after the learning session. The teacher gave a score

of 89.2%, which falls into the Very Practical category, while students gave a score of 84.6%, also in the Very Practical category. The average practicality score for this cycle was 86.9%.

Effectiveness Results (Cycle 1)

Effectiveness was measured through pre-test and post-test. The average pre-test score was 48.2 and the average post-test score was 68.4, showing an increase of 20.2 points. Normality tests showed that the data were normally distributed ($p > 0.05$), and the paired sample t-test showed significant results ($p = 0.000$). The N-Gain obtained was 0.58 (Moderate category), while the Effect Size (Cohen's d) was 0.89 (Large category).

Identification of Problems and Revisions Based on Cycle 1

Based on classroom observations, teacher interviews, and analysis of student test results in Cycle 1, several problems were identified that needed immediate improvement. These problems were grouped into spatial literacy aspects and technical aspects as presented in Table 2.

Table 2. Problem Identification in Cycle 1 – Limited Trial

No	Aspect	Problems Found
1	Spatial Visualization	Students had difficulty imagining the unseen parts of three-dimensional objects from two-dimensional representations (e.g., the back edges of a cube that are hidden). They only viewed objects from one perspective and could not imagine the complete shape.
2	Spatial Orientation	Students were unable to determine the positions of points, lines, or planes after the object was rotated or the perspective was changed. When AR displayed the object from a different side, students became confused and lost orientation.
3	Spatial Relations	Students often made errors in distinguishing between parallel lines, intersecting lines, and skew lines in three-dimensional space. They tended to equate line concepts in two-dimensional planes with those in three-dimensional space.
4	Spatial Representation	Students had difficulty connecting two-dimensional representations in textbooks or worksheets with three-dimensional objects displayed through AR. They could not translate between different representations.
5	Technical Constraints	Some students were not yet familiar with the GeoGebra 3D AR interface, requiring additional time to learn the available features. AR feature activation sometimes required a stable internet connection and an adequate phone camera.
6	Student Activeness	Students tended to be passive and waited for teacher instructions before trying to explore AR features. They lacked initiative to explore independently.

Based on these identified problems, revisions were made to the e-module as presented in Table 3.

Table 3. Revisions Made Based on Cycle 1 – Limited Trial

No	Aspect	Revision Made
1	Spatial Visualization	Added step-by-step visual guides showing how to rotate and observe AR objects from various angles. Added directional arrow indicators to help students understand the viewing direction.
2	Spatial Orientation	Added automatic rotation animations that slowly display objects from various perspectives. Added interactive orientation exercises that ask students to identify element positions after rotation.
3	Spatial Relations	Added line visualizations on 3D objects that can be selected separately (highlight buttons for each line type). Students can clearly see which lines are parallel, intersecting, or skew.
4	Spatial Representation	Added splitscreen feature displaying two-dimensional images on the left and AR models on the right simultaneously. Added transition questions that train students to connect both representations.

5	Technical Constraints	Added interactive tutorial at the beginning of the e-module in the form of short video guides on how to use all features. Added "Help" buttons on every menu to assist students experiencing difficulties.
6	Student Activeness	Added independent exploration instructions on each page encouraging students to try available features. Added challenges/quests that motivate students to explore and discover geometric concepts on their own.

After all revisions were completed, E-Module Version 2.0 was produced and ready to be re-tested with the same group in Limited Trial Cycle 2.

Practicality Results (Cycle 2)

After revisions, e-module version 2.0 was re-tested with the same group. The results showed significant improvement. The teacher gave a score of 94.3% (an increase of 5.1% from Cycle 1), and students gave a score of 91.8% (an increase of 7.2%). The average practicality score became 93.05% with a Very Practical category. This improvement indicates that the revisions successfully made the e-module easier to use. Students reported that the visual guides and interactive tutorials were very helpful in operating the AR features. The teacher also assessed that the exploration challenges successfully increased student activeness.

Effectiveness Results (Cycle 2)

Effectiveness measurement in Cycle 2 showed even better improvement. The average post-test score increased from 68.4 in Cycle 1 to 78.6 in Cycle 2. The paired sample t-test remained significant ($p = 0.000$). N-Gain increased from 0.58 to 0.68 (Moderate category, approaching High). Most importantly, Effect Size (Cohen's d) increased from 0.89 to 1.12, now falling into the Very Large category. This effect size increase of 0.23 proves that the revisions made truly improved the product quality. The e-module effectiveness based on Ismawati et al.'s (2021) criteria reached 68% (Fairly Effective category). Although this category is moderate, when associated with the very large effect size, the e-module has substantially proven to be effective.

Decision

Since practicality reached an average of 93.05% (Very Practical) and effectiveness showed an effect size of 1.12 (Very Large), the limited trial was stopped at Cycle 2. The product, revised from both cycles, was named E-Module Version 3.0 and was ready for testing on a larger scale in the field trial.

Field Trial

The field trial was conducted with a larger group to test the e-module's practicality and effectiveness in more realistic classroom conditions. The field trial involved 64 students from two vocational high schools: 32 students from SMK TKM Purworejo and 32 students from SMK YPP Purworejo, with 2 mathematics teachers (one from each school). Similar to the limited trial, practicality and effectiveness were measured simultaneously in two cycles on the same subjects.

Practicality Results (Cycle 1)

In the first cycle of the field trial, e-module version 3.0 was applied to a larger group. Teachers gave an average practicality score of 87.5% (Very Practical category), while students gave a score of 83.2% (Very Practical category). The average practicality score for this cycle was 85.35%. Although still in the very practical category, this score was slightly lower compared to the limited trial Cycle 2. This is reasonable because the larger group had more diverse characteristics and abilities, requiring additional adjustments. Some teachers reported that in schools with limited facilities, AR feature activation took longer. Additionally, students from different backgrounds required varying adaptation times.

Effectiveness Results (Cycle 1)

In the first cycle of the field trial, the average pre-test score was 46.5 and the average post-test score was 65.8, showing an increase of 19.3 points. Normality tests showed that the data were normally distributed ($p > 0.05$), and the paired sample t-test showed significant results ($p = 0.000$). The N-Gain obtained was 0.55 (Moderate category), while the Effect Size (Cohen's d)

was 0.82 (Large category). These findings confirm that the e-module remained effective with the larger group, although the effect was slightly lower compared to the limited trial.

Identification of Problems and Revisions Based on Cycle 1

Based on observations, teacher interviews, and analysis of test results in the field trial Cycle 1, several new problems emerged when the e-module was applied to a larger and more diverse group, as presented in Table 4.

Table 4. Problem Identification in Cycle 1 – Field Trial

No	Aspect	Problems Found
1	Internet Connection	Not all students had stable internet connections. AR feature activation requiring internet access was often constrained in schools with inadequate networks.
2	Diversity of Technology Skills	Students had varying levels of technology proficiency. Some students adapted quickly to AR features, while others needed more time and extra guidance.
3	User Interface	Some students felt that the e-module interface was still too complicated, especially for navigation between pages and AR display settings.
4	Challenge Duration	The challenges/quests provided were considered too difficult for some students, especially those using AR technology for the first time.
5	Device Limitations	Not all students had phones with specifications that optimally supported AR features. Some phones experienced lag or delays when displaying 3D objects.

Based on these identified problems, revisions were made to the e-module to adapt to the more diverse field conditions.

Table 5. Revisions Made Based on Cycle 1 – Field Trial

No	Aspect	Revision Made
1	Internet Connection	Added offline guides in PDF format that can be accessed without internet connection. AR features remained accessible but were supplemented with alternative instructions if connection issues occurred.
2	Diversity of Technology Skills	Added video tutorials that can be played anytime without internet connection. These videos explain in detail how to use each e-module feature.
3	User Interface	Simplified user interface by reducing non-essential buttons and menus. Navigation was made more intuitive with clearer icons**.**
4	Challenge Duration	Challenge duration and complexity were adjusted to better match average student ability. Challenges were made progressive from easy to more difficult**.**
5	Device Limitations	Added recommended device specification guides and ways to optimize phone settings for smoother AR performance.

After all revisions were completed, E-Module Version 4.0 was produced and ready to be re-tested with the same group in Field Trial Cycle 2.

Field Trial (Cycle 2)

Revisions Tested in Cycle 2

In Cycle 2 of the field trial, the e-module being tested had undergone improvements from Cycle 1. These improvements were specifically designed to address the five main problems that emerged with the larger and more diverse group. First, to address internet connection constraints, offline guides in PDF format were added that can be accessed without internet. Second, to address the diversity of technology skills among students, video tutorials that can be played anytime were added. Third, to make usage easier, the user interface was simplified with more intuitive navigation. Fourth, challenge duration and complexity were adjusted to be more progressive and suitable for average student ability. Fifth, to address device limitations,

recommended device specification guides and ways to optimize phone settings were added. All these improvements were tested on the same group to verify whether the revisions truly improved the e-module's practicality and effectiveness on a larger scale.

Practicality Results (Cycle 2)

After revisions, e-module version 4.0 was re-tested with the same group. The results showed significant improvement. Teachers gave an average score of 92.1% (an increase of 4.6% from Cycle 1), and students gave a score of 89.7% (an increase of 6.5%). The average practicality score became 90.9% with a Very Practical category. This improvement indicates that the revisions successfully addressed the constraints that emerged in the first cycle. Teachers reported that the offline guides and video tutorials were very helpful, especially in schools with limited internet access. Students also felt more comfortable using the e-module with the simplified interface.

Effectiveness Results (Cycle 2)

Effectiveness measurement in Cycle 2 of the field trial showed better improvement. The average post-test score increased from 65.8 in Cycle 1 to 76.4 in Cycle 2. The paired sample t-test remained significant ($p = 0.000$). N-Gain increased from 0.55 to 0.65 (Moderate category, approaching High). Effect Size (Cohen's d) increased from 0.82 to 1.04, now falling into the **Very** Large category. This effect size increase of 0.22 proves that the revisions made in the field trial Cycle 1 truly improved product quality. The e-module effectiveness based on Ismawati et al.'s (2021) criteria reached 65% (Fairly Effective category).

Decision

Since practicality reached an average of 90.9% (Very Practical) and effectiveness showed an effect size of 1.04 (Very Large), the field trial was stopped at Cycle 2. The final product of the entire development series is the GeoGebra 3D AR E-Module Final Version, ready for wide implementation in mathematics learning, particularly for three-dimensional geometry material in vocational high schools.

Table 6. Recapitulation of Practicality and Effectiveness Across All Cycles

Phase	Cycle	**Subjects**	Practicality (%)	N-Gain	Effect Size (d)	Description
Limited Trial	Cycle 1	32 students (SMK Muhammadiyah)	86.9	0.58	0.89	Very Practical / Large
	Cycle 2	32 students (SMK Muhammadiyah)	93.05	0.68	1.12	Very Practical / Very Large
Field Trial	Cycle 1	64 students (SMK TKM & SMK YPP)	85.35	0.55	0.82	Very Practical / Large
	Cycle 2	64 students (SMK TKM & SMK YPP)	90.9	0.65	1.04	Very Practical / Very Large

DISCUSSION

The primary novelty of this research lies in the synergistic integration of three previously separate pedagogical and technological elements: Van Hiele's hierarchical geometry syntax, the deep learning approach, and GeoGebra 3D Augmented Reality, into a single coherent interactive e-module for three-dimensional geometry in vocational high schools. While prior studies have examined augmented reality or Van Hiele's model in isolation (Arifin et al., 2020; Dimla & Soriano, 2019), no existing work has combined these components in a way that maps Van Hiele's visualization, analysis, and informal deduction phases directly onto AR-supported exploration activities embedded within a deep learning framework. Furthermore, this study introduces a methodological innovation through its two-cycle iterative trial procedure in which practicality and effectiveness are measured simultaneously on the same subjects in each cycle, ensuring that every revision is empirically verified for its impact on product quality rather than assumed to be beneficial. This approach departs from conventional R&D procedures that test practicality and effectiveness on separate groups without re-validating the effect of revisions, thereby offering a more rigorous standard for development research in mathematics education.

This design rationale is consistent with research showing that 3D augmented-reality representations can support learning about spatial relationships, although learners' prior spatial abilities and visualization design influence the benefits they receive (Krüger et al., 2022; Koparan et al., 2023).

The main findings of this study demonstrate that the GeoGebra 3D AR e-module achieved a very valid category from expert validation with an average of 86.25%, with the media feasibility aspect obtaining the highest score at 90%. In the limited trial, practicality increased from 86.9% in Cycle 1 to 93.05% in Cycle 2, while the effect size increased from 0.89 (Large) to 1.12 (Very Large). In the field trial involving a larger and more diverse group, practicality increased from 85.35% to 90.9%, and the effect size increased from 0.82 to 1.04. These results are significant because they demonstrate that the e-module is not only technically and pedagogically sound but also empirically effective in improving students' spatial literacy, with each revision cycle producing measurable and substantial gains in both practicality and learning outcomes. The consistent improvement across all cycles confirms that the iterative revision process based on identified field problems directly contributed to the enhancement of product quality.

These findings align with several previous studies on the use of GeoGebra and AR in mathematics education. Arifin et al. (2020) found that AR media on GeoGebra met validity criteria for geometry learning, which is consistent with the 90% media feasibility score obtained in this study. Dimla and Soriano (2019) reported that AR-based learning materials improved students' spatial visualization skills, a finding that resonates with the significant effect sizes observed in both the limited and field trials of this research. Suprapto et al. (2021) demonstrated that GeoGebra-based teaching materials were practical for vocational school students, which corresponds with the very practical category achieved throughout all trial cycles in this study. Ismawati et al. (2021) established effectiveness criteria for educational products that were adopted in this research, and the 65–68% effectiveness scores obtained here fall within the fairly effective range consistent with their framework. However, this study extends beyond these prior works by demonstrating that the integration of AR into GeoGebra, when combined with Van Hiele's syntax and the deep learning approach, produces substantially larger effect sizes than those typically reported for single-component interventions. Additionally, the finding that effect size is more informative than N-Gain in assessing product effectiveness, as evidenced by the N-Gain remaining in the moderate category while effect size reached the very large category, offers a methodological insight that diverges from the more commonly reported N-Gain-based evaluations in R&D studies.

A recent systematic review examined the integration of augmented reality in mathematics and its relationship with spatial and geometric learning (Izzati et al., 2026). Research in the Indonesian context has also examined augmented reality implementation and mathematical spatial ability (Rihadatul 'Aisy et al., 2025). Additional reviews have focused specifically on the effects of augmented reality on students' spatial abilities and its use as a learning medium (Nabila & Malasari, 2026; Sani et al., 2026). A separate systematic review has considered the role of augmented reality in supporting conceptual understanding of geometry (Muhammad et al., 2026). Research on GeoGebra use in mathematics learning in Indonesia has examined its relationship with students' learning outcomes (Suhaifi et al., 2022). A separate study investigated GeoGebra-assisted learning and students' mathematical communication ability (Kurniawan & Ulfah, 2023). Recent review work has also examined students' spatial ability in GeoGebra-assisted mathematics learning (Meirani et al., 2026). Research on augmented reality in geometry learning further highlights the need to align the media with appropriate learning activities (Susilowati et al., 2025).

The similarities between this study's findings and those of previous research can be attributed to several converging factors. The consistent validity and practicality results across studies reflect the well-established pedagogical value of GeoGebra as a dynamic mathematics tool that supports visualization and exploration, a principle that has been widely documented in mathematics education literature. The positive effects on spatial literacy align with cognitive load theory (Sweller, 2011) and experiential learning theory (Dewey, 1938), both of which

predict that concrete, interactive visual representations reduce extraneous cognitive load and facilitate meaningful learning. The differences observed, particularly the larger effect sizes in this study compared to prior single-component interventions, may be explained by the synergistic combination of multiple pedagogical elements. While previous studies used AR or Van Hiele's model separately, this research integrated them within a deep learning framework, creating a more comprehensive learning experience that addresses both the technological and pedagogical dimensions of geometry learning. The slightly lower practicality and effectiveness scores in the field trial compared to the limited trial can be attributed to differences in research context and population. The field trial involved a larger and more diverse group of students from two different schools with varying levels of technological infrastructure, internet connectivity, and device specifications, all of which introduced additional variables that influenced the implementation of the e-module. These contextual factors required additional revisions, such as offline guides and simplified interfaces, which were not necessary in the more controlled limited trial setting. This interpretation is also consistent with findings that visualization design and learner characteristics can interact, meaning that AR should be scaffolded rather than treated as a universally effective stand-alone intervention (Kühl et al., 2022; Nagy-Kondor & Esmailnia, 2022; Jaber et al., 2023).

The contribution of this research to the field of mathematics education and development research is twofold. Theoretically, it advances the understanding of how Van Hiele's hierarchical levels of geometric reasoning can be operationalized through AR-supported exploration activities within a deep learning framework, providing a concrete model for translating abstract pedagogical theory into practical learning media. Methodologically, it establishes a more rigorous standard for R&D research by demonstrating that the iterative two-cycle procedure with simultaneous measurement of practicality and effectiveness on the same subjects produces empirically validated products and ensures that each revision is verified for its actual impact. This procedure addresses a significant gap in the existing R&D literature, where revisions are often made without systematic verification of their effectiveness, and where practicality and effectiveness are typically tested on separate groups, making it difficult to attribute improvements to specific revisions. The finding that effect size is a more sensitive and informative measure than N-Gain for detecting product improvement also contributes to the methodological discourse in educational research.

The practical implications of this research are substantial for vocational high school mathematics education. The GeoGebra 3D AR e-module can be widely implemented because it is accessible through students' personal smartphones, requiring no special device investment from schools. Teachers can use this e-module as an alternative to overcome students' difficulties in understanding three-dimensional geometry, particularly in schools with limited resources and facilities. The offline guides and video tutorials developed during the field trial revisions ensure that the e-module remains accessible even in schools with inadequate internet connectivity, making it a viable solution for diverse educational contexts. For future research, it is recommended that the e-module be tested on a broader scale involving more schools and diverse student populations to further validate its effectiveness and practicality. Additionally, future studies could explore the integration of other emerging technologies, such as virtual reality or artificial intelligence, to further enhance the interactive and adaptive capabilities of the e-module. From a policy perspective, the findings suggest that vocational high schools should consider incorporating AR-based learning media into their mathematics curricula, and that teacher training programs should include preparation for using such technologies to ensure successful implementation. The methodological contribution of this research also has implications for educational researchers, who may adopt the iterative two-cycle procedure with simultaneous measurement as a standard for future R&D studies to produce more rigorously validated educational products.

CONCLUSION

This research has successfully developed an interactive e-module based on Van Hiele learning with a deep learning approach assisted by GeoGebra 3D Augmented Reality to

stimulate vocational high school students' spatial literacy. The development followed the ADDIE model through five systematic stages: Analysis, Design, Development, Implementation, and Evaluation. The resulting product integrates Van Hiele syntax (visualization, analysis, and informal deduction), deep learning principles (meaningful exploration, projects, and reflection), and GeoGebra 3D AR technology into a single interactive e-module designed to address the fundamental challenges of three-dimensional geometry learning in vocational schools.Based on the research findings, the e-module is declared very valid with an average validation score of 86.25%, with media feasibility receiving the highest score of 90% and language feasibility receiving 82%, both in the very valid category. The e-module is also very practical, with practicality reaching 93.05% in the limited trial (32 students at SMK Muhammadiyah Purworejo) and 90.9% in the field trial (64 students from SMK TKM Purworejo and SMK YPP Purworejo). Furthermore, the e-module is proven effective in improving spatial literacy, evidenced by significant paired sample t-test results ($p < 0.05$) in all trial cycles, N-Gain of 0.68 (moderate category) in the limited trial and 0.65 (moderate category) in the field trial, and Effect Size (Cohen's d) of 1.12 (very large category) in the limited trial and 1.04 (very large category) in the field trial. The consistency of results across different school contexts confirms the robustness of the e-module's effectiveness.

The implication of this research is that the use of AR-based learning media integrated with Van Hiele syntax and a deep learning approach can become an innovative alternative in geometry learning, helping teachers create more gradual, meaningful, and student-centered learning experiences. Theoretically, this research contributes to development research methodology by demonstrating that the iterative cycle procedure with simultaneous measurement is more rigorous and can serve as a methodological standard for future R&D research. Research limitations include the relatively limited sample sizes and the use of a one-group pretest-posttest design without a control class. Future research is advised to use stronger experimental designs involving control groups and larger sample sizes to further validate the effectiveness of this e-module across different populations and contexts.

REFERENCES

Adams, J., Resnick, I., & Lowrie, T. (2023). Supporting senior high-school students' measurement and geometry performance: Does spatial training transfer to mathematics achievement? Mathematics Education Research Journal, 35, 879–900. https://doi.org/10.1007/s13394-022-00416-y

Anan Sutisna, M. P. (2021). *Metode Penelitian Kualitatif Bidang Pendidikan*. UNJ PRESS. Google Scholar

Anna, UHL, Chamot. (2005). Language learning strategy instruction: current issue and research, *annual review of applied linguistic.* Volume 25, No. 1, p. 12-130. Retrieved 06 May, 2019. From: https://doi.org/10.1017/S0267190500061

Arnal-Bailera, A., & Manero, V. (2024). A characterization of Van Hiele's level 5 of geometric reasoning using the Delphi methodology. International Journal of Science and Mathematics Education, 22, 537–560. https://doi.org/10.1007/s10763-023-10380-z

Ary, D., Jacobs, L. C., & Sorensen, C. (2010). *Introduction to research in education*. USA: Wadsworth. Google Scholar

Asna, A. N., Soedjoko, E., & Mariani, S. (2021). Description of Van Hiele's geometry thinking ability in solving open ended problems in the 7E-Learning Cycle in terms of self efficacy. Unnes Journal of Mathematics Education, 10(1). https://doi.org/10.15294/ujme.v10i1.31245

B., Geoffrey, Brumfit, C., Falvell, R., Peter, H., and Pincas , A. (2003). *Teaching English as foreign language*. University of London institute of education: Routledge London and New York Google Scholar

Balla, Ervin. (2016). A general outlook of the importance of the English language in the world today. *Academic journal of inter disciplinary studies*. Volume 5, No. 3, p. 499-503. Retrieved 04 May, 2019. http://dx.doi.org/10.5901/ajis.2016.v5n3s1p499

Chang, H.-Y., Binali, T., Liang, J.-C., Chiou, G.-L., Cheng, K.-H., Lee, S. W.-Y., & Tsai, C.-C. (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. Computers & Education, 191, 104641. https://doi.org/10.1016/j.compedu.2022.104641

Cozma, Mihaela. (2015). The challenge of teaching English to adult learners in today"s world. *Procedia-social and behavioral sciences*. Volume 197, p. 1209-1214. Retrieved 04 May, 2019. https://doi.org/10.1016/j.sbspro.2015.07.380

del Cerro Velázquez, F., & Morales Méndez, G. (2021). Systematic review of the development of spatial intelligence through augmented reality in STEM knowledge areas. Mathematics, 9(23), 3067. https://doi.org/10.3390/math9233067

Dilling, F., & Vogler, A. (2021). Fostering spatial ability through computer-aided design: A case study. Digital Experiences in Mathematics Education, 7, 323–336. https://doi.org/10.1007/s40751-021-00084-w

Fitrianingsih, E. Y., Akhyar, M., & Efendi, A. (2023). Augmented reality development opportunities in geometry learning for elementary students. Jurnal Pendidikan dan Pengajaran, 56(1), 114–125. https://doi.org/10.23887/jpp.v56i1.51238

Herlianawati, A., Lestari, L., & Suwono, M. (2017, October). Learning English through the Use of Classroom Language in Community Service. In *Social Sciences, Humanities and Economics Conference (SoSHEC 2017)* (pp. 81-86). Atlantis Press. https://dx.doi.org/10.2991/soshec-17.2018.16

Izzati, A. A. T., Sa'dijah, C., Arifin, S., Dewi, R. S. I., & Ekawati, R. (2026). Integrating augmented reality in mathematics: A mixed-methods systematic review of spatial and geometric learning. Jurnal Inovasi Teknologi Pendidikan, 13(2), 143–159. https://doi.org/10.21831/jitp.v13i2.85197

Jaber, O., Swidan, O., & Fried, M. N. (2023). Design considerations in developing an augmented reality learning environment for engaging students in covariational reasoning. International Journal of Emerging Technologies in Learning, 18(11), 52–73. https://doi.org/10.3991/ijet.v18i11.38923

Johnson, T., Burgoyne, A. P., Mix, K. S., Young, C. J., & Levine, S. C. (2022). Spatial and mathematics skills: Similarities and differences related to age, SES, and gender. Cognition, 218, 104918. https://doi.org/10.1016/j.cognition.2021.104918

Kattlen Cotton . (2001). *Principals and students achievement*. Alexandria: association for supervision and curriculum development. Google Scholar

Koparan, T., Dinar, H., Koparan, E. T., & Haldan, Z. S. (2023). Integrating augmented reality into mathematics teaching and learning and examining its effectiveness. Thinking Skills and Creativity, 47, 101245. https://doi.org/10.1016/j.tsc.2023.101245

Krüger, J. M., Palzer, K., & Bodemer, D. (2022). Learning with augmented reality: Impact of dimensionality and spatial abilities. Computers and Education Open, 3, 100065. https://doi.org/10.1016/j.caeo.2021.100065

Kühl, T., Fehringer, B. C. O. F., & Münzer, S. (2022). Unifying the ability-as-compensator and ability-as-enhancer hypotheses. Educational Psychology Review, 34, 1063–1095. https://doi.org/10.1007/s10648-021-09650-5

Kurniawan, I., & Ulfah, S. (2023). Effects of the Geogebra-assisted Missouri mathematics project learning model on students' mathematical communication ability. Jurnal Riset Pendidikan Matematika, 10(2), 175–185. https://doi.org/10.21831/jrpm.v10i2.60232

Lightbown, P.M, and Spada, N. (2006). *How language are learned*. Oxford: Oxford university press

Marguerite, Lodico, Pean. T, Spaulding, Ketherine. (2006). *Methods in educational research from theory to practice*. San Francisco: Josses-bass.

Megawati, F. (2016). Kesulitan mahasiswa dalam mencapai pembelajaran bahasa Inggris secara efektif. *PEDAGOGIA: Jurnal pendidikan*, *5*(2), 147-156. https://doi.org/10.21070/pedagogia.v5i2.246

Meirani, A. P., Waluya, S. B., Zaenuri, & Walid. (2026). Students' spatial ability in GeoGebra-assisted mathematics learning: A systematic literature review. Media Pendidikan Matematika, 14(1), 77–92. https://doi.org/10.33394/mpm.v14i1.19018

Meirida, U., Johar, R., & Ahmad, A. (2021). Pengembangan lintasan belajar limas untuk mengembangkan kemampuan spasial siswa melalui pendidikan matematika realistik berbantuan GeoGebra. PYTHAGORAS: Jurnal Matematika dan Pendidikan Matematika, 16(1), 1–18. https://doi.org/10.21831/pg.v16i1.36157

Moule, P., & Hek, G. (2011). *Making sense of research: An introduction for health and social care practitioners*. Sage.

Muchlis, E. E., Priatna, N., & Dahlan, J. A. (2021). Development of a web-based worksheet with a project-based learning model assisted by GeoGebra. Jurnal Riset Pendidikan Matematika, 8(1), 46–60. https://doi.org/10.21831/jrpm.v8i1.40985

Muhammad, H., Musa, N. A., Ahmad, A., Adamu, N., & Adamu, N. (2026). The role of augmented reality (AR) in enhancing conceptual understanding of geometry in mathematics education: Systematic review. International Journal of Education, Management, and Technology, 4(1), 29–47. https://doi.org/10.58578/ijemt.v4i1.8073

Nabila, A. R., & Malasari, P. N. (2026). The effect of augmented reality on students' spatial abilities in mathematics learning: A systematic literature review. Jurnal Math Educator Nusantara, 12(1), 193–211. https://doi.org/10.29407/jmen.v12i1.27993

Nagy-Kondor, R., & Esmailnia, S. (2022). Development of spatial ability extra tasks (SAET): Problem solving with spatial intelligence. Quality & Quantity, 56, 3751–3768. https://doi.org/10.1007/s11135-021-01284-7

Nan, L. 2020. A Survey on Thai University Students ' Use of English Outside of the Classroom : A Survey on Thai University Students ' Use of English Outside of the Classroom : A Case Study (August). Google Schoolar

Rihadatul 'Aisy, L., Cahyono, A. N., Zaenuri, & Walid. (2025). Implementation of augmented reality in mathematics learning on mathematical spatial ability. Media Pendidikan Matematika, 13(2), 1088–1103. https://doi.org/10.33394/mpm.v13i2.18487

Sani, A., Lestari, D., Putri, V. M., Arif, D. F., Rozi, F., & Permatasari, M. (2026). The utility of augmented reality (AR) learning media in improving mathematical spatial abilities in Indonesia: A systematic literature review. International Journal of Academic Studies in Technology and Education, 4(1). https://doi.org/10.55549/ijaste.83

Scollon, Ron. (1991). Topic confusion on English-Asian discourse. *Suzanne wong-scollen*. Volume 10, No. 3. p. 456-465. Retrieved 03 April, 2019. https://doi.org/10.1111/j.1467-971X.1991.tb00145.x

Souriyavongsa, T., Rany, S., Jafre Zainol Abidin, M. & Lai Mei, L. 2013. Factors Causes Students Low English Language Learning: A Case Study in the National University of Laos. *International Journal of English Language Education* 1(1): 179–192. Google Scholar

Stanzione, C. & Schick, B. 2014. Environmental language factors in theory of mind development: Evidence from children who are deaf/hard-of-hearing or who have specific language impairment. *Topics in Language Disorders* 34(4): 296–312. doi:10.1097/TLD.0000000000000038. Google Scholar

Suhaifi, A., Rufii, & Karyono, H. (2022). Pengaruh penggunaan aplikasi GeoGebra terhadap hasil belajar matematika. Jurnal Inovasi Teknologi Pendidikan, 8(2), 220–230. https://doi.org/10.21831/jitp.v8i2.45080

Suprapto, E., Setyansah, R. K., & Devina, D. (2021). GeoGebra application based tutorial materials to improve spatial mathematics abilities in vocational high schools. Jurnal Pendidikan Teknologi dan Kejuruan, 27(2), 175–181. https://doi.org/10.21831/jptk.v27i2.39099

Yang, Y., Du, W., Mavrikis, M., et al. (2026). Spatial skill development through augmented reality in mathematics education: A scoping review. Digital Experiences in Mathematics Education, 12, 277–310. https://doi.org/10.1007/s40751-025-00187-8