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MATHEMATICS EDUCATION

Developing GeoGebra 3D-assisted interactive e-worksheet for composite solids visualization

Dianis Ahmad Faizal [1,*], **Afit Istiandaru** [1]

[1] Department of Mathematics Education, Universitas Ahmad Dahlan, Yogyakarta, Indonesia
*Corresponding author

Abstract

Spatial ability is crucial in geometry learning; however, students frequently experience misconceptions when visualizing intersecting 3D composite solids, a challenge conventional static materials fail to address. Therefore, this study aims to develop, validate, and evaluate the practicality of an interactive electronic student worksheetusing Lumi education integrated with GeoGebra 3D dynamic applets. Applying the ADDIE development model, the e-worksheet features independent 3D object manipulation, composite solid decomposition simulations, scaffolding trigger questions, an "anti-forget formula" reference panel, and adaptive interactive evaluations. Product validity was assessed by material and media experts, while practicality was evaluated through small-group and field tests involving 10th-grade students at SMA Negeri 1 Bambanglipuro, a public high school in Yogyakarta, using Likert-scale questionnaires analyzed via descriptive statistics. Results indicate that the e-worksheet achieved "strongly valid" and "practical" criteria. The interactive 3D manipulations effectively reduced cognitive load and resolved surface area misconceptions. This product significantly enriches innovative interactive learning references for geometry visualization. Based on these evaluations, future research is recommended to incorporate gamification elements, optimize practice question portions, and conduct comprehensive effectiveness testing on students' spatial skills.

Keywords: composite solids, interactive e-worksheet, GeoGebra, Lumi education, visualization media

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Correspondence address: Department of Mathematics Education, Universitas Ahmad Dahlan, Jalan Ahmad Yani, Tamanan, Banguntapan, Bantul, Yogyakarta, 55191, Indonesia. E-mail: 2200006038@webmail.uad.ac.id

INTRODUCTION

Spatial ability is one of the crucial and fundamental competencies in mathematics learning, particularly in the domain of geometry. This ability enables students to mentally visualize, manipulate, and analyze three-dimensional objects before translating them into mathematical calculations (Octaviani et al., 2021; Rasyidah et al., 2023). When solving geometric problems, students undergo a gradual cognitive and mental process based on the Van Hiele theory, starting from the visualization or basic shape recognition stage, followed by analysis or component description, informal deduction or ordering of geometric properties, formal deduction, and ultimately reaching the level of rigor or high logical accuracy (Unaenah et al., 2020). To successfully navigate these stages, students must possess excellent spatial abilities. This ability is characterized by students' proficiency in determining the actual size or shape of a geometric solid based on a specific observational perspective, transforming three-dimensional objects into various forms, precisely rotating objects mentally, determining the hierarchical relationship of an object with its surroundings, and determining the complete representation of a geometric solid when viewed from various different angles (Farihah et al., 2025).

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However, in practice, many students encounter significant difficulties in mastering this visual competency, particularly when faced with complex problem-solving tasks such as composite geometric solids (Putri & Nurul, 2018). These difficulties align closely with the findings of various previous studies, which demonstrate a strong correlation between students' mathematical abilities and their level of spatial reasoning. Specifically, students with lower mathematical abilities exhibit major constraints in visualizing, detailing, and connecting the components of complex geometric objects (Kurniawan & Fitriyani, 2024; Musriroh et al., 2021). This stagnant condition underscores the urgent need for innovation in both teaching methods and the development of instructional materials specifically designed to enhance spatial abilities in geometry (Istaria, 2021; Mispriatin, 2022).

Based on preliminary observations conducted by the researcher at SMA Negeri 1 Bambanglipuro, it was found that the availability and utilization of electronic-based instructional materials, such as electronic student worksheet (e-worksheet), remain minimal. The instructional materials routinely utilized by educators are largely dominated by supplementary textbooks and PowerPoint presentations. This is despite the fact that visual media play a crucial role in learning, as they can significantly enhance students' comprehension. Various forms of visual media, such as images, diagrams, and animations, enable students to access and comprehend information more efficiently (Wahidin, 2025). In practice, educators at the school have indeed attempted to integrate e-worksheet into their teaching; however, their utilization is frequently limited to presenting digital text in PDF format. Consequently, the interactive potential of such electronic media remains underdeveloped and requires further optimization. Furthermore, interview results revealed that students openly admit to struggling with visualizing the spatial forms of geometric solids unless the teacher provides similar concrete objects in the classroom. This deficiency in visualization capacity has a detrimental impact when students are tasked with solving analytical word problems or deconstructing the constituent structures of composite geometric solids.

Three-dimensional geometry topics are generally taught at the junior high school level (Grade 9). Based on the current curriculum, by the end of Phase D, students are required to possess measurement competencies, which include determining the surface area and volume of geometric solids (such as prisms, cylinders, spheres, pyramids, and cones) and solving related problems. The scope of this topic is comprehensive and strictly demands strong spatial abilities from students. For instance, students are tested on their ability to visualize how a two-dimensional net can be logically folded into a complete three-dimensional geometric solid. More crucially, in the topic of composite solids, students must be able to visualize which faces overlap and should thus be excluded from the surface area calculation, as well as mentally manipulate the object when deconstructing the composite solid into several basic shapes prior to calculating its total volume. These mental manipulation skills essentially represent a direct application of spatial ability indicators derived from the previously described Van Hiele levels of geometric thought.

With the rapid advancement of educational technology, the utilization of digital instructional media offers a highly promising solution to overcome these spatial ability challenges. One prominent innovation is the use of the Lumi H5P application. This application enables the creation of various multimedia contents, such as quizzes, interactive videos, presentations, and simulations, which can be operated both offline and online (Maria Imakulata Ina Talu et al., 2025). The implementation of Lumi H5P provides convenience for both teachers and students due to its simple and interactive interface, allowing it to be used independently by students or during classroom instruction with the teacher (Maria Imakulata Ina Talu et al., 2025). The advantages of Lumi are further optimized when integrated with dynamic mathematics software such as GeoGebra. GeoGebra has long been proven effective in accurately presenting two-dimensional (2D) and three-dimensional (3D) concepts (Tamam & Dasari, 2021). Supported by the embed feature on the Lumi platform, GeoGebra applets can be seamlessly integrated into the e-worksheet. This seamless integration creates an exploratory learning environment where students are not required to open separate applications; they can actively rotate the perspectives of 3D geometric solids, dissect the interior of composite solids, and assemble or disassemble geometric components directly within a single worksheet interface. Such direct interaction significantly minimizes students' cognitive load in visualizing complex spatial structures (Fitriani et al., 2019; Woro Kurniasih et al., 2018).

Although the utilization of both e-worksheet and GeoGebra has been widely investigated separately in various educational contexts (Novianti et al., 2023; Yanti et al., 2024), an extensive literature review reveals a fundamental research gap. Currently available e-worksheet generally have room for further optimization regarding their level of interactivity. Furthermore, the application of GeoGebra in classrooms holds the potential to be elevated from a mere demonstration tool to an independent exploration space for students, particularly in crucial topics such as composite geometric solids. Therefore, this study focuses on offering novelty through the development of a fully integrated e-worksheet that combines the robustness of Lumi Education with the dynamic features of GeoGebra 3D applets. The primary contribution of this article is to provide an innovative and empirically tested alternative instructional media for geometry to address misconceptions regarding the area of overlapping faces caused by students' weak spatial abilities. Simultaneously, it serves as a practical reference for curriculum developers in designing instructional materials based on digital visual manipulation. Based on this comprehensive exposition, the research questions addressed in this study focus on determining the validity level of the interactive e-worksheet based on Lumi Education assisted by GeoGebra for the topic of composite geometric solids, as evaluated by subject matter and media experts, as well as assessing its practicality based on the evaluative responses of teachers and students in the field. In alignment with these research questions, the primary goals of this study are to test the feasibility or validity and to precisely measure the practical implementation of this interactive e-worksheet as an innovative instructional media.

RESEARCH METHOD

This study employs a Research and Development (R&D) design. This approach was selected as it aligns with the primary objectives of the research, namely to design, develop, validate, and test the practicality of a tangible product in the form of instructional media (Rotang, 2025). The innovative product developed in this study is an interactive e-worksheet based on the Lumi Education platform, fully integrated with dynamic GeoGebra 3D applets, and specifically focused on geometric problem-solving related to composite solids.

Development model

The development procedure in this study adapts the stages of the ADDIE model, which consists of five systematic and interconnected phases: Analysis, Design, Development, Implementation, and Evaluation.

In the analysis phase, the researcher conducted a series of fundamental needs analyses in the field, encompassing an analysis of students' cognitive characteristics, curriculum analysis (specifically the Learning Outcomes for surface area and volume measurement topics), as well as an analysis of the availability and limitations of geometry instructional media currently utilized by educators.

In the design phase, the researcher developed the media framework (storyboard), formulated a concept map for the topic of composite geometric solids, structured learning activities that align with the Deep Learning approach, designed a user-friendly interface, and compiled the assessment blueprints along with the research instruments in the form of questionnaires.

In the development phase, the e-worksheet was technically produced utilizing Lumi H5P and GeoGebra software. Upon the completion of the initial prototype, the instructional media underwent a validation process by lecturers and experts to evaluate its theoretical and instructional feasibility prior to field implementation.

In the implementation phase, the instructional media, revised based on expert feedback, was field-tested directly with the research subjects at the school to observe actual user interactions and assess the practicality level of the e-worksheet.

In the evaluation phase, a comprehensive analysis of all validation data and field test results was conducted to assess the attainment of the objectives and refine the product into its final form, ready for distribution.

Participants and testing procedure

The subjects in this study were categorized into two primary groups, namely expert validators and field test subjects. The expert validators consisted of subject matter experts and media experts. The evaluation by subject matter experts focused on the accuracy of geometric concepts and pedagogical feasibility, whereas the media expert evaluation concentrated on the functionality of the H5P features and the operational fluidity of the GeoGebra 3D manipulation system.

Meanwhile, regarding the field test subjects, the initial target population for this instructional material was Grade 9 junior high school students. However, considering the field circumstances wherein the data collection coincided with the conclusion of the academic year for Grade 9 students, the trial subjects were shifted to Grade 10 students at SMA Negeri 1 Bambanglipuro. The selection of Grade 10 students was grounded in sound academic reasoning; they serve as the closest proxy for the recently graduated Grade 9 students, having thoroughly completed the prerequisite materials at the previous educational level, and possessing sufficient cognitive maturity to deliver objective evaluations regarding the navigation and practicality of the e-worksheet. The field trial was executed in two phases: a small group trial to identify preliminary technical constraints, and a large group field trial to evaluate the practicality of the e-worksheet in a real-world learning setting.

Data collection instrument

The data collection method was conducted utilizing non-test techniques in the form of questionnaires. There were two primary instruments: the expert validation questionnaire and the practicality (user response) questionnaire. The questionnaires were designed using a Likert Scale format with five qualitative response alternatives, which were subsequently quantified into scores: Very Good/Strongly Agree (score of 5), Good/Agree (score of 4), Fair/Neutral (score of 3), Poor/Disagree (score of 2), and Very Poor/Strongly Disagree (score of 1). Additionally, an open-ended comment section was provided to record qualitative suggestions and critiques, serving as a basis for product revisions.

Data analysis technique

Qualitative data, comprising critiques and suggestions from both the validators and the trial subjects, were collected and analyzed using a narrative descriptive approach to serve as a fundamental guideline for product refinement. Conversely, quantitative data derived from the Likert Scale questionnaire scores were analyzed using descriptive statistics to determine the ideality percentage. The formula employed to calculate the percentage of the instructional media's feasibility (validity) and practicality levels is as in Equation (1) (Palelupu & Cholik, 2014).

$$K = \frac{F}{N \times I \times R} \times 100\% \tag{1}$$

Note:

K = Percentage of eligibility

F = Total score obtained from respondents
N = Maximum score in the questionnaire
I = Number of items (questions) in the questionnaire
R = Number of respondents

After obtaining the percentage (K), the value is converted into qualitative categories to draw assessment conclusions. Based on the five-scale conversion criteria guideline (Palelupu & Cholik, 2014), the percentage intervals for feasibility and practicality are established as seen in Table 1.

Table 1. Validity and practicality criteria categories

Percentage	Validity Criteria	Practicality Criteria
$0\% \le K \le 20\%$	Highly invalid	Highly impractical
$20\% < K \le 40\%$	Invalid	Impractical
$40\% < K \le 60\%$	Less valid	Less practical
$60\% < K \le 80\%$	Valid	Practical
$80\% < K \le 100\%$	Strongly valid	Very practical

In this development research, an e-worksheet product is deemed eligible and ready for use if it achieves a minimum criterion of "valid" in the validity aspect and "practical" in the aspect of field user responses.

RESULTS AND DISCUSSION

This research and development have resulted in a final product in the form of an interactive e-worksheet) assisted by GeoGebra for the material of composite 3D shapes. Based on the stages of the ADDIE development model outlined in the research methods, this section will elaborate in detail on the results of the development, implementation, and evaluation stages, along with a comprehensive discussion of the findings throughout the research process.

The developed e-worksheet

During the development stage, the initial storyboard was realized into a complete digital product using the Lumi Education platform based on the HTML5 (H5P) framework. This e-worksheet was designed not merely to serve as a digital form of a printed book (such as a static PDF format), but rather as an interactive learning environment that facilitates a deep learning approach. The material on composite 3D shapes is presented through a series of structured activities that guide students ranging from observing and manipulating to independently drawing conclusions.

The primary advantage of the developed product lies in the seamless integration between the Lumi platform and the GeoGebra 3D dynamic applet. Through the Iframe Embedder feature in Lumi, simulations of composite 3D shapes, such as the illustration of breaking down a medicine capsule into cylinder and hemisphere forms, as well as a house model, can be embedded directly. This enables students to engage in touch-based interactions, such as rotating the camera perspective 360 degrees, dragging sliders to disassemble and reassemble the components of the 3D shapes, and observing changes in surface area and volume variables in real-time. The series of activities within this e-worksheet is equipped with an instant feedback feature in the "Champion's Challenge" quiz section, as well as a "My Reflection Journal" feature to facilitate students' metacognitive stages at the end of the learning process.

Contextual evaluation and problem-solving

In the e-worksheet, there is a problem-solving activity involving real-world word problems to calculate the surface area of a building, as exemplified in Figure 1. In Figure 1, students are required to translate mathematical narratives into spatial forms by utilizing the 3D simulation from GeoGebra positioned side-by-side with the word problem. The expected capability in this activity is that students are able to engage in higher-order thinking skills (HOTS), analyze problems, and logically realize that overlapping faces in composite shapes (such as the roof base and the ceiling) are excluded from the calculation or painting. Based on the trial, students appeared capable of identifying building dimension components meticulously and no longer experienced confusion when visualizing 3D shapes from a text description. This indicates that the use of real-world contexts combined with 3D simulations is highly effective as an ultimate solution to overcome misconceptions regarding composite surface area calculations.

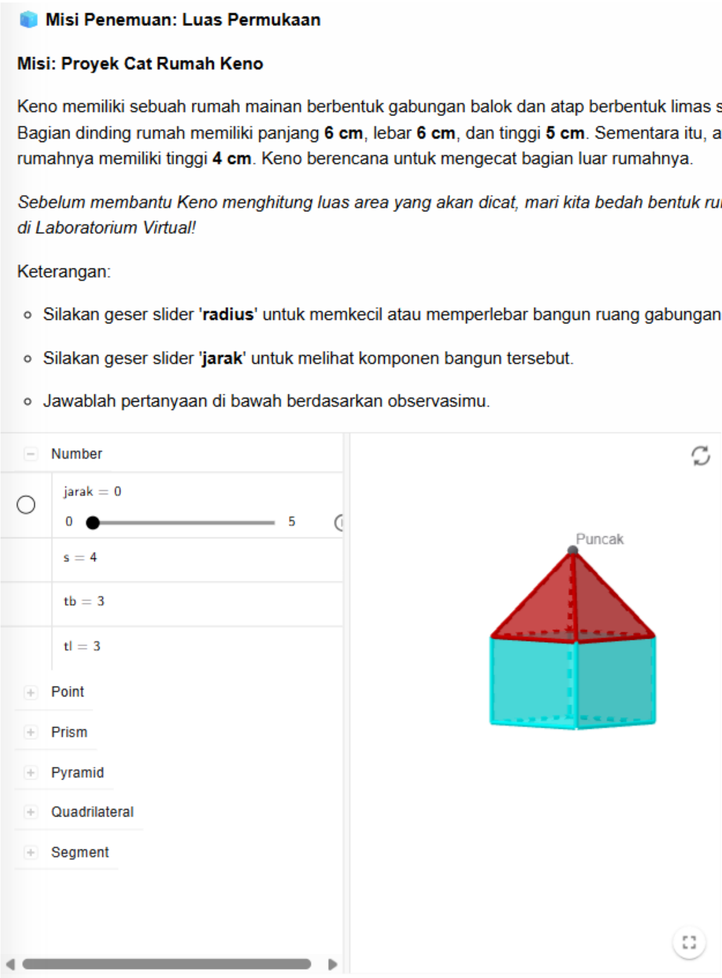

Figure 1. E-worksheet interface for the discovery mission section.

Understanding and visual observation stage

In the e-worksheet, there are activities involving interacting with and observing 3D models of composite geometric shapes, as exemplified in Figure 2. In Figure 2, students are instructed to rotate the viewing angle of the image and virtually dismantle the shape to examine its constituent basic forms, followed by answering a brief quiz to recall its fundamental formulas. The capability expected in this activity is that students are able to visualize and decompose complex shapes into simpler parts prior to performing mathematical calculations. Based on the trial, students appeared capable of identifying the constituent shapes quickly and accurately, aided by the interactive 3D visualization. This indicates that direct interaction with 3D objects effectively builds a strong conceptual foundation and optimally facilitates the initial stages of deep learning.

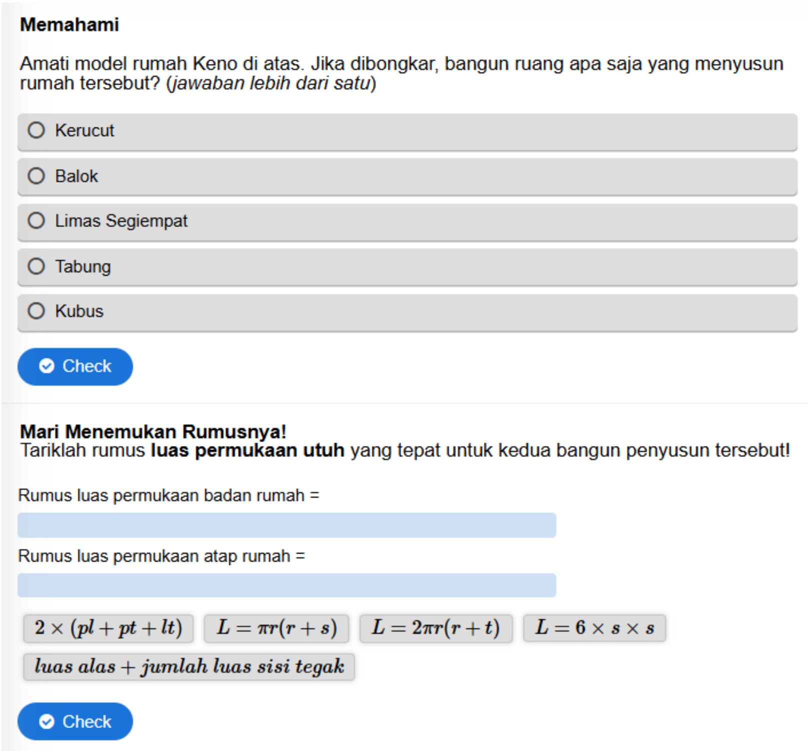

Figure 2. E-worksheet interface for the understanding section.

Applying and formula construction stage

In the e-worksheet, there is an activity to analyze the condition of geometric shapes when they are combined, as exemplified in Figure 3. In Figure 3, students are required to evaluate the area of overlapping faces through guided interactive questions and independently construct the appropriate formula for the composite shape. The expected capability in this activity is for students to engage in meaningful learning by discovering the formula independently, rather than merely receiving and memorizing an instant formula. Based on the trial, students appeared capable of formulating mathematical equations correctly and became significantly more careful regarding the overlapping faces of the shapes. This indicates that guiding students to construct their own knowledge gradually is highly effective in preventing misconceptions in advanced geometric concepts.

Cognitive assistance/formula reference feature

In the e-worksheet, there is an "Anti-Forget Formula" (Rumus Anti-Lupa) feature that contains a collection of basic formulas for single 3D shapes, as exemplified in Figure 4. In Figure 4, students are encouraged to utilize this formula reference panel whenever they experience confusion or memory lapses while constructing new formulas or solving practice problems. The expected capability in this activity is for students to manage their independent learning without experiencing cognitive overload. Based on the trial, students appeared to be significantly aided and proceeded more smoothly through the problem-solving stages, as their mental energy was not depleted solely by the process of recalling basic formulas. This indicates that the provision of easily accessible cognitive scaffolding can fully optimize students' focus on the analytical stage of problem-solving.

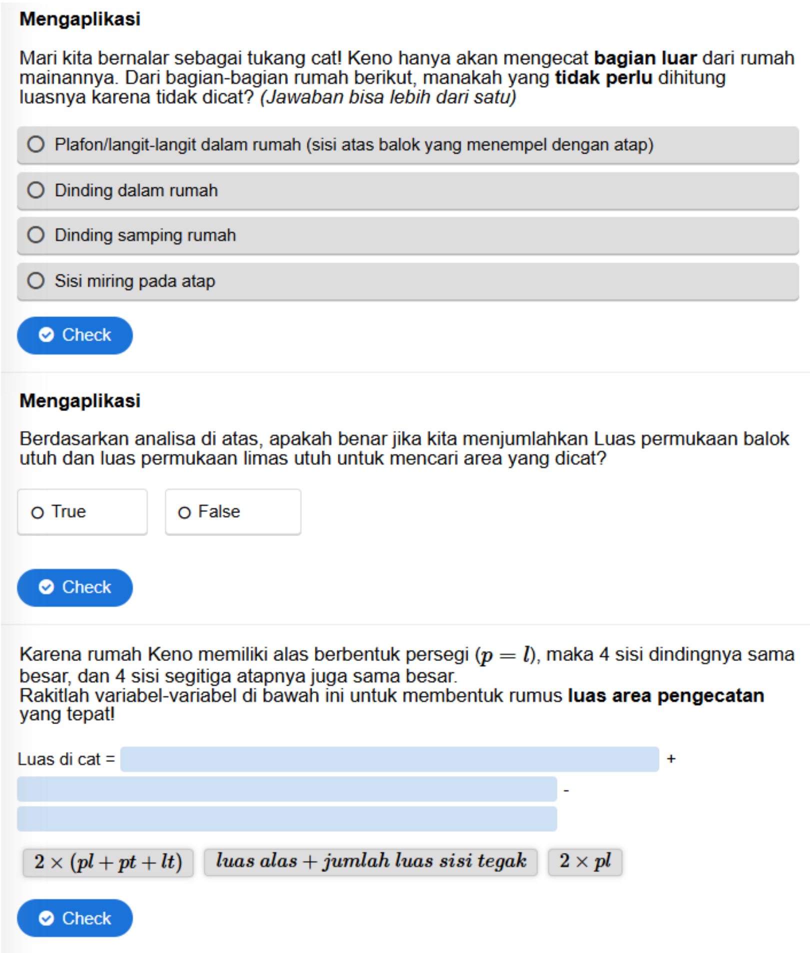

Figure 3. E-worksheet interface for the application section

Evaluation results

Prior to field implementation, the e-worksheet was first validated by lecturers and expert teachers acting as material and media experts. This assessment aimed to ensure the theoretical feasibility, conceptual accuracy, and technical functionality of the developed media.

Content validation results

The evaluation by the material expert focused on four main aspects: content feasibility, language feasibility, presentation feasibility, and the fulfillment of the deep learning approach. Overall, the material on composite 3D shapes was deemed accurate and free from mathematical misconceptions. Nevertheless, based on the initial assessment results, the validator provided a critical note that the indicators for the deep learning aspect received relatively lower scores compared to the other aspects. The validator suggested the necessity of incorporating scaffolding into the trigger questions to make the students' process of discovering the formula for overlapping faces more meaningful. Based on the calculation of the post-revision questionnaire data using the feasibility percentage formula, the material expert assigned a score of 88%. According to the conversion criteria table, this figure falls within the range categorized as "strongly valid".

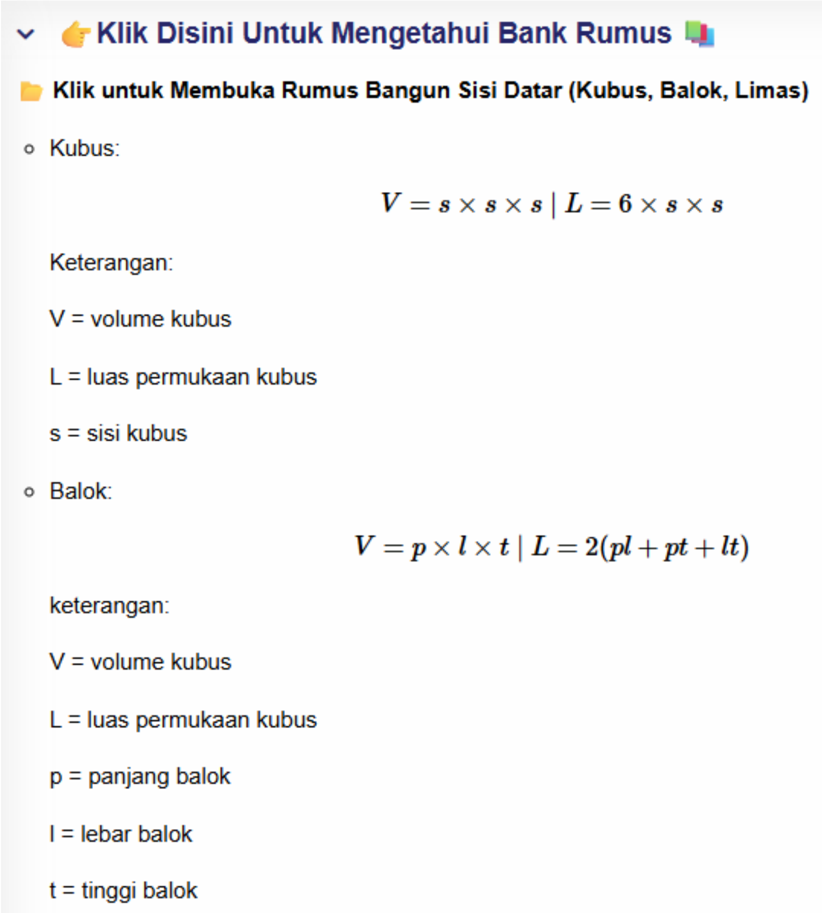

Figure 4. E-worksheet interface for the formula bank section

Media validation results

The media evaluation focused on aspects of technical functionality, User Interface (UI), and User Experience (UX) navigational comfort. The media validation process was conducted systematically through a self-evaluation that was intensively consulted with the academic supervisor. The focus of the evaluation included testing the smoothness of the drag-and-drop function, text readability, transitions between H5P pages, and the responsiveness of the GeoGebra applet across various screen sizes. The evaluation results concluded that the media technically operated exceptionally well without any system failures (bugs); therefore, it was declared feasible to proceed to the field trial stage.

Table 2. Content validation results

	Total Score	Percentage	Criteria
Material	44	88%	Strongly valid

Practicality test

The e-worksheet product, which had been declared valid, was subsequently implemented with the test subjects, specifically 10th-grade students at SMA Negeri 1 Bambanglipuro. The testing process was carried out in two stages to collect comprehensive practicality data.

Small group
This initial trial stage involved six students with heterogeneous cognitive abilities. The objective was to identify any technical and instructional issues before implementing the media in a whole-class setting. Overall, student responses at this stage were quite positive, as they found the 3D visualizations helpful. Nevertheless, several disruptive technical (UX) issues were identified, including a truncated submit button interface on certain smartphone screens and a font size deemed too small, which reduced reading comfort. These feedbacks were promptly addressed by the researcher by adjusting the Iframe dimensions and increasing the font size within the Lumi system.

Large group
Following the technical revisions, the e-worksheet was tested in a whole-class setting involving 27 tenth-grade students and one mathematics teacher. At this stage, student enthusiasm increased significantly. The majority of students provided qualitative feedback indicating that the rotatable and dismantlable 3D shape features significantly facilitated their ability to visualize overlapping faces, a visualization challenge that has traditionally been difficult to overcome using printed books.

Although the overall responses were highly satisfactory, there was constructive criticism from the test subjects concerning cognitive load. The students indicated that the excessive number of practice questions in the e-worksheet induced fatigue and drowsiness during completion. Furthermore, there was a suggestion to provide an offline access mode to anticipate internet connection instability at the school. Accommodating these feedbacks, the researcher reduced the quantity of questions to prioritize the depth of analytical understanding, ensuring that the students' interaction time with the media became more ideal and meaningful. Based on the quantitative analysis of the practicality questionnaire, the responses from the 27 students yielded a feasibility percentage of 78%. Referring to the criteria conversion interval, this percentage consistently indicates that the developed e-worksheet falls into the "practical" category.

Table 3. Practicality test results

Respondents	Total Score	Percentage	Criteria
Students	1056	78%	Practical

Discussion
The data analysis results from the development, expert validation, and field trial stages demonstrate that this GeoGebra-assisted interactive e-worksheet serves as a learning media solution that is not only academically valid, but also practical and well-received by users. The primary finding of this research confirms the theoretical foundation outlined in the introduction section, wherein the utilization of GeoGebra technology is proven to be crucial in bridging the limitations in students' spatial visualization skills.

Previously, students frequently experienced misconceptions when calculating the surface area of composite 3D shapes because they tended to sum the total surface areas of the constituent shapes without considering the overlapping faces. The inclusion of 3D simulations in this e-worksheet disrupts the habit of rote formula memorization. Through the decomposition slider feature, students can concretely observe how combining two 3D shapes "eliminates" one or two of their outer surface faces. This direct interaction builds a robust procedural and conceptual understanding, aligned with the principles of constructivism in deep learning.

Regarding the feedback from the material expert validator concerning the low deep learning scores during the initial development phase, this provides a crucial insight that technological sophistication alone is insufficient without appropriate instructional design (scaffolding). The incorporation of contextual narratives, logical guiding questions, and the provision of a "Reflection Journal" (Jurnal Refleksi) at the end of the learning process serve as a bridge that transforms this e-worksheet from a mere visual demonstration tool into a meaningful learning instrument.

On the other hand, the findings from the field trial underscore the importance of the User Experience (UX) aspect in the development of digital teaching materials. Obstacles such as truncated buttons across various smartphone screen resolutions affirm that a mobile-friendly and responsive media design is an absolute prerequisite in today's digital education era. Furthermore, student complaints regarding fatigue caused by an excessive number of practice questions indicate that students' attention capacity towards interactive media has a certain threshold. The reduction in the number of questions conducted by the researcher did not diminish the essence of the material; rather, it optimized students' cognitive time allocation to focus on the analysis and exploration stages of the 3D applet, instead of merely getting trapped in mechanical calculation activities (drilling). It is this cyclical series of evaluations and revisions that ultimately ensures this e-worksheet product fulfills the criteria of high validity and practicality.

CONCLUSION

Based on the research and development stages utilizing the ADDIE model, this study has successfully produced an interactive e-worksheet assisted by GeoGebra via the Lumi education platform for composite 3D geometry. The testing results indicate that this interactive E-WORKSHEET fulfills the "Very Valid" criteria based on evaluations by material and media experts, signifying both its conceptual and technical feasibility. Furthermore, the field implementation at SMA Negeri 1 Bambanglipuro demonstrated that this media achieved the "Practical" criteria based on the responses of the mathematics teacher and students. Notably, the interactive 3D manipulation feature proved effective in reducing cognitive load and minimizing misconceptions regarding the visualization of overlapping faces.

Overall, the successful integration of this media demonstrates that the GeoGebra-assisted interactive e-worksheet effectively facilitates the enhancement of students' spatial skills in understanding composite 3D shapes. Nevertheless, to optimize the potential of utilizing this media in learning, future research is recommended to refine this e-worksheet by incorporating gamification elements to increase interactivity and adjusting the proportion of practice questions to achieve an ideal workload. In addition to design refinements, a quantitative effectiveness test should also be conducted in subsequent studies to measure the direct impact of using this media on students' spatial ability achievement.

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DECLARATION

Author contribution

All authors contribute in the research and/or writing the paper, and approved the final manuscript.

Dianis Ahmad Faizal	Conceptualizing the research idea, leading the investigation, setting up the methodology, analyzing data, and writing the first draft.
Afit Istiandaru	Assisting the investigation, reviewing the validity of the methodology, enriching the data analysis, and approving the final draft.

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Conflict of interest
All authors declare that they have no competing interests.

Ethics declaration
We as authors acknowledge that this work has been written based on ethical research that conforms with the regulations of our institutions and that we have obtained the permission from the relevant institutes when collecting data. We support the Bulletin of Applied Mathematics and Mathematics Education (BAMME) in maintaining the high standards of personal conduct, practicing honesty in all our professional practices and endeavors.

The use of artificial intelligence
We do not use any generative AI tools to write any part of this paper.

Additional information
Not available.

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APPENDIX
For more details, please visit https://app.lumi.education/run/y9z6C9 to see the whole e-worksheet.