





# Developing GeoGebra-Based Interactive Learning Media for Teaching Relations and Functions in a Wetland Cultural Context

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**Abstract.** This study aimed to develop an interactive learning medium based on GeoGebra and JavaScript for the topic of relations and functions, incorporating the cultural context of wetland environments such as traditional foods, regional songs, and other local elements. The development process followed the ADDIE model—analysis, design, development, implementation, and evaluation. The product was evaluated through validity testing by content and media experts, as well as practicality and effectiveness testing. The results showed that the developed medium was valid in both content and technical aspects. It was also considered practical based on teacher and student questionnaire responses. Effectiveness testing using a paired sample t-test yielded a p-value  $< 0.05$ , indicating a significant improvement between pre-test and post-test scores. The Cohen's d value of 3.53 indicated a very large effect size, with statistical power of 1.00, demonstrating high reliability. Therefore, the developed interactive learning medium is considered valid, practical, and effective for use in contextual mathematics learning on the topic of relations and functions.

**Keywords:** Interactive Learning Media, GeoGebra, Relations and Functions.

## 1 Introduction

Mathematics is still perceived by most students as a difficult subject, including the topic of relations and functions. Research by [1] showed that more than 60% of students struggle to understand the concepts of relations and functions, including difficulties in distinguishing between the two, grasping their definitions, and performing related operations. As a fundamental topic and prerequisite for more advanced mathematics, a lack of understanding in this area can hinder further learning progress.

Given the abstract nature of mathematics, educators need to design engaging and meaningful learning experiences. The rapid advancement of technology provides opportunities for teachers to utilize various technology-based learning media that capture students' attention. The integration of technology in learning can enhance interactivity, support more dynamic learning experiences, and provide access to a wide range of information sources [2].

One form of technology-based learning media that teachers can use is interactive learning media. This type of media is designed not only to present theoretical explanations but also to include example problems, practice exercises, and evaluation questions [3] [4]. Due to its interactive nature, the media can respond to user actions, allowing it to function not only as a learning resource but also as a tutor for students. Multimedia components such as text, images, audio, and video can further enhance interactivity and foster deeper understanding [5] [6] [7].

In mathematics education, GeoGebra stands out as a widely used, free, cross-platform tool that supports the visualization of mathematical concepts. Research has shown that GeoGebra positively influences students' conceptual understanding, critical thinking, independence, and learning engagement [8] [9] [10].

GeoGebra files that have been created can be utilized in the learning process either by accessing them directly via the GeoGebra website or by sharing the file links through e-learning platforms such as Google Classroom. However, to further streamline learning management, these files can also be embedded directly into web pages [11] [12], allowing for a more cohesive digital learning environment.

This study aims to develop interactive learning media on the topic of relations and functions using GeoGebra and JavaScript. The topic is contextualized with the local wetland culture of South Kalimantan. The results of this study are expected to support teachers in integrating technology into mathematics instruction, thereby creating an enjoyable, student-centered learning experience.

## 2 Research Methods

This study is a developmental research employing the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation [13] [14]. The research procedures are described as follows: The analysis stage involves a content needs analysis and software requirements analysis. The content analysis includes examining the teaching material in accordance with the curriculum and identifying appropriate pedagogical approaches. The software requirements analysis identifies the software tools needed to develop the learning media, based on the results of the content analysis.

The design stage consists of designing the media flowchart, use case diagram, and compiling teaching materials based on the needs analysis. The teaching materials were validated by four mathematics education experts from the Faculty of Teacher Training and Education (FKIP), Lambung Mangkurat University. The instrument used to assess the validity of the materials included three indicators: content feasibility, presentation feasibility, and language appropriateness [15].

The development stage involves producing the interactive learning media based on the validated design. The output of this stage is an interactive learning media on the topic of Relations and Functions. The media was validated by four media experts from FKIP Lambung Mangkurat University. The instrument used to evaluate the media was adapted from the Learning Object Review Instrument, covering three aspects: feedback and adaptation, presentation design, and interaction usability [7] [16].

The implementation stage consists of a trial session using the developed and validated media. The trial was conducted in the multimedia lab of SMPN 14 Banjarmasin, South Kalimantan, Indonesia, involving 15 students from class VII-H. The implementation was carried out over six sessions. The purpose of the trial was to assess the practicality and effectiveness of the learning media. The practicality instrument was adapted from [6] [17], and included indicators such as ease of use and navigation, knowledge space and information presentation, aesthetics, and ease of learning. The effectiveness of the learning media was measured based on students' pretest and post-test scores.

The evaluation stage was conducted at the end of each phase as an immediate corrective step during the development process. The evaluation aimed to collect data regarding the validity, practicality, and efficiency of the developed learning media. The validity of both the content and the media was assessed using a 4-point rating scale, ranging from score 1 (poor) to score 4 (excellent). The learning materials and media were considered valid if the average score obtained was at least 3.0.

The practicality of the learning media was obtained through a response questionnaire administered after the use of the media. The questionnaire was constructed using a Likert scale, with scores ranging from 1 (strongly disagree), 2 (disagree), 3 (agree), to 4 (strongly agree). The learning media was considered practical if the average response score was at least 3.0.

The effectiveness of the learning media was evaluated based on students' pretest and posttest scores. To measure this effectiveness, an inferential analysis was conducted using a Paired Sample t-test to compare the results before and after the use of the media. In addition, the effect size was calculated using Cohen's *d* to determine the magnitude of the media's impact, and a power analysis was performed to assess the statistical power of the test.

Interactive media can be considered effective if there is a statistically significant improvement in students' scores after the intervention. Such improvement indicates that the media successfully supports the learning process and facilitates the achievement of instructional objectives. Effectiveness is further supported by additional statistical measures such as the effect size (e.g., Cohen's *d*) and post hoc statistical power, which confirm that the observed effects are both meaningful and reliable.

### **3 Results and Discussion**

All stages of the research process were completed successfully. Based on the content analysis, the developed learning media integrates multiple components—including text, images, diagrams, mathematical notations, and graphs—to enhance conceptual understanding. Additionally, it features interactive elements, particularly within the presentation of materials and problem-solving sections—both example problems and exercises.

To enhance interactivity, the development of the media involved not only GeoGebra, but also required the integration of other applications to support additional features. In this case, JavaScript was used. As stated by [18] [19], JavaScript can be utilized

to create dynamic and interactive web applications, and to add advanced features including audio, video, SVG, and drag-and-drop functionality.

Furthermore, to display mathematical symbols on the web pages, the KaTeX library was employed. KaTeX is a JavaScript library used to render mathematical expressions quickly and accurately in web environments [20] [21]. Table 1 shows the main technologies used in the development process.

**Table 1.** Technologies Used in the Development

Function	Technology
Structuring the content of the learning media	HTML
Styling the elements in HTML	CSS
Enabling interactivity on web pages	JavaScript
Designing responsive web pages	Bootstrap
Creating interactive math exercises	GeoGebra
Rendering mathematical notations on web pages	KaTeX
Storing practice and evaluation data	Firebase

The selection of technologies presented in Table 1 was based on the specific needs of developing interactive, web-based learning media that are both functional and accessible to students. Each technology was chosen for its particular strength in supporting the development process:

- HTML and CSS serve as the foundational components for building and styling the structure of the web-based media. HTML allows for the systematic organization of content, while CSS enhances the visual appearance to improve readability and user engagement.
- JavaScript was used to enable interactivity within the learning media. This scripting language allows dynamic responses to user actions—such as providing immediate feedback or animating visual elements—thereby enhancing learner engagement and interactivity.
- Bootstrap was integrated to ensure that the media is responsive, meaning it can adapt seamlessly to different screen sizes and devices, including desktops, tablets, and smartphones. This is particularly important to support accessibility and usability in various learning environments.
- Firebase was employed as a cloud-based backend service to store user data such as exercise results and evaluation outcomes. Its real-time database and authentication features facilitate secure and efficient data management without requiring a dedicated server.
- GeoGebra was selected due to its strength in supporting dynamic mathematical visualizations. It enables the development of interactive exercises that align with the mathematical content being taught, especially in the topic of relations and functions.

- KaTeX, a fast and reliable JavaScript library for rendering mathematical expressions, was used to display mathematical notation clearly and accurately on web pages. This is essential for maintaining the mathematical integrity of the content.

Overall, the integration of these technologies ensures that the resulting learning media is not only pedagogically sound but also technically robust, interactive, and accessible for middle school students.

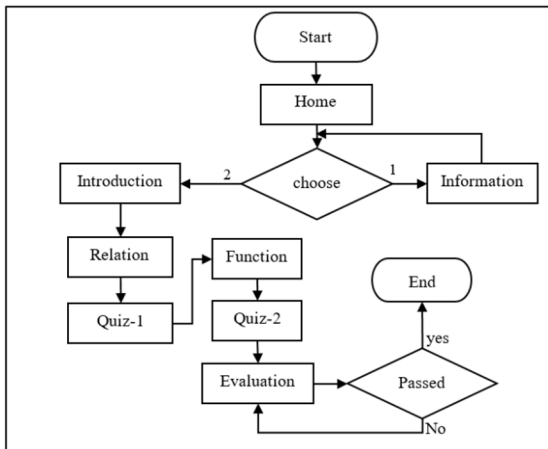


Fig. 1. Flowchart of user navigation and learning evaluation process

At the design stage, a media flowchart and use case diagram were developed to visualize the structure and user interaction within the learning media. The flowchart outlines the sequence of user actions (see Fig. 1), while the use case diagram identifies the system functionalities accessible to different users (see Fig. 2).

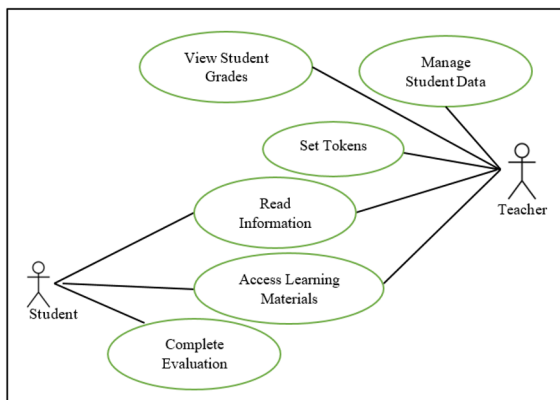


Fig. 2. Use case diagram

In the design phase, contextual elements derived from local culture were embedded into the instructional materials. Integrating local cultural elements aligns with the principles of Contextual Teaching and Learning (CTL), which facilitate students in connecting abstract mathematical concepts with real-life experiences. Problems and activities were designed using scenarios involving traditional foods (such as ketupat kandangan and lempeng pisang), regional songs (like Ampar-Ampar Pisang), and traditional games (such as balogo and engklek). These culturally relevant contexts were incorporated into examples and exercises to help students better understand topics such as relations and functions in a familiar setting—thereby enhancing both engagement and comprehension.

The interactive learning media for the topic of Relations and Functions has been successfully developed. The application can be accessed via the link: <https://mtkrelasidanfungsismp.netlify.app/>. Teachers can manage the learning process through the teacher's page, while students can begin learning by clicking the "Start Learning" button. Upon clicking this button, users are directed to the Materials Page, which contains learning objectives, explanations of the material, example problems, and practice exercises.

After completing the practice exercises, users can proceed to answer the competency test questions provided at the end of each sub-topic. The learning materials include explanatory text and images related to the topic of relations and functions. Certain parts of the material are designed to be interactive. This aligns with [22], which states that interactivity is one of the most essential elements in the learning process. Through this feature, it is expected that students will remain focused and actively engaged throughout the learning process [23]. Furthermore, as emphasized by [22], interactivity within an application can significantly enhance user engagement, even in the absence of direct guidance from a teacher or facilitator.

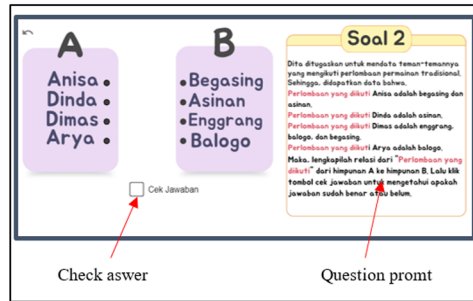
At the end of each sub-topic, an interactive practice session is provided. Users can respond to each question, and the application will automatically check whether the answer is correct. These practice problems were created using GeoGebra. The GeoGebra-based exercises are embedded into the HTML document pages using the `<iframe></iframe>` tag, as the following example shows:

```
<iframe scrolling="no"
title="soal9wrhweiwehrjfbmsdhiwekfs"
src=https://www.GeoGebra.org/material/iframe/id/czwxyamd/
width/960/height/450/bor-
der/fff/sfsb/true/smb/false/stb/false/stbh/false/ai/false
/asb/false/sri/false/rc/false/ld/false/sdz/false/ctl/fals
e
width="960px" height="450px" style="border:0px;">
</iframe>
```

The developed learning media includes a total of 49 practice questions, all of which are interactive. The interactivity in the practice section is designed to provide immediate feedback on users' answers. The direct feedback given by the application encourages users to respond, thereby creating a two-way interaction that makes the learning

process more enjoyable and motivates students to learn [24] [25]. Further-more, immediate feedback is expected to help prevent students from repeating the same mistakes and to support the reinforcement and retention of their understanding [26]. This feedback mechanism is applied to all types of practice questions.

The application offers various question types, including multiple-choice, activity-based, and short-answer questions. In the example shown in Fig. 3, users are also informed of the question prompt and answer options. Upon answering each question, users are prompted to click the “Check Answer” button (see Fig. 3).



**Fig. 3.** Screenshot of a practice question interface. The annotated boxes show the functions: “Check Answer” (button to submit and validate an answer), and “Question prompt” (the question prompt text).

In this exercise, the user is asked to drag a point from a member of set A to the corresponding member of set B, forming an arrow. After clicking the “Check Answer” button, if the user’s answer is incorrect, an error message will appear and a “Retry” button will be shown as illustrated in Fig. 4.



**Fig. 4.** Example of error message display for practice questions in the application

If the user's answer is correct, a message indicating the correct answer and an explanation will be displayed. The user will no longer be able to drag or move the arrow. An example of the correct answer display can be seen in Figure 5.

Features such as the “Check Answer” and “Retry” buttons align with the phases of active experimentation and reflective observation in Kolb’s learning cycle. Users are able to immediately observe the consequences of their responses (concrete experi-

ence), receive feedback (reflective observation), process and understand the rationale (abstract conceptualization), and then try again (active experimentation). The inclusion of explanations following correct answers serves as scaffolding that helps users consolidate their understanding, in accordance with Kolb’s theory of learning styles and the concept of learning space that supports the overall learning process [26].

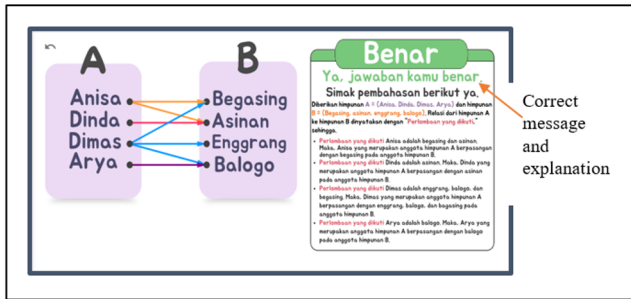


Fig. 5. Example of correct message display for practice questions in the application

In addition to the practice exercises at the end of each subtopic, the application provides a set of 10 multiple-choice questions designed to assess users’ understanding of the material they have studied. Upon completing all questions, users immediately receive their score. Users are allowed to retake the competency test multiple times until they achieve the desired result.

Furthermore, at the end of the learning module, a comprehensive evaluation is provided to assess the users’ overall understanding of the material. This evaluation consists of 20 multiple-choice questions. Similar to the competency test, the score is displayed immediately after completion, and users may repeat the evaluation as needed to improve their results.

All scores from both the competency tests and the final evaluation are stored and made accessible on the teacher's dashboard. Teachers can download students' performance data in either PDF or Excel format for further analysis and documentation.

The next stage in media development involved validation by content experts and media experts. The validity level of the learning material was assessed based on evaluations conducted by a content expert in the field of Mathematics Education. The results of the material validation are presented in Table 2.

Table 2. Material expert validation

Aspect	Average score
Content	2.40
Presentation	3.25
Language	3.50
Contextualization	3.25
Overall	3.35

Table 2 shows that the average validation score for the material was 3.35, which falls into the “high validity” category. The validation results from the content expert indicate that the material on relations and functions is valid and can be used with minor revisions. The material is considered valid because it aligns with the intended learning objectives, is appropriate for the target users—namely, students at the low-er secondary school level—and the exercises provided are relevant to the concepts being taught.

The media validation was conducted by a media expert to assess the quality and usability of the interactive learning application. The assessment covered several aspects including feedback and adaptation, presentation design, and interaction usability. The average score from the validation results is presented in Table 3.

**Table 3.** Media expert validation

Aspect	Average score
Feedback and adaptation	4.00
Presentation design	3.50
Interaction usability	3.13
Overall	3.54

The overall media validity score, based on the four validators, was 3.54, which is categorized as high validity. These results indicate that the developed interactive learning media is appropriate for use in the trial implementation phase, with minor revisions.

A classroom trial was conducted to examine the practicality and effectiveness of the developed interactive learning media. The learning session was implemented in an of-line (face-to-face) format. Students accessed the media individually on computers available in the school’s multimedia laboratory using the Google Chrome browser.

Throughout the session, the researcher collaborated with the classroom teacher to support the students. The teacher was responsible for initiating the lesson, providing access to the learning content via a link and token for the interactive media, offering explanations when students raised questions, and guiding them during the learning process.

**Table 4.** Results of user response questionnaire on media practicality

Aspect	Average score
Ease of use and navigation	3.27
Content quality and cognitive demand	3.24
Aesthetic design	3.38
Learning support effectiveness	3.47
Overall functionality	3.42
Overall average	3.34

The practicality of the interactive learning media was evaluated using a user response questionnaire, which included five key aspects: Ease of Use and Navigation, Content

Quality and Cognitive Demand, Aesthetic Design, Learning Support Effectiveness, and Overall Functionality. The results, presented in Table 4, show that all aspects received average scores above 3.0, with an overall mean score of 3.34, indicating that the media is considered practical for classroom use.

The highest score was recorded in the Learning Support Effectiveness aspect (3.47), suggesting that the media effectively facilitated students' understanding of the material. This aligns with the intended pedagogical design of the media, which incorporates interactive and guided learning elements to enhance cognitive engagement.

With an overall average score of 3.34, the learning media can be classified as practical for classroom implementation. These findings reinforce the conclusion that the developed interactive media is not only functional but also well-received by students in terms of usability and learning support.

To measure the students' learning outcomes, a pre-test and post-test were administered, each consisting of 20 multiple-choice questions. The normality of the data was tested using the Shapiro-Wilk test, and the results are shown in Table 5.

**Table 5.** Normality test results

Test type	p-value	W	N	Average score
Pre-test	0.7411	0.9628	15	38.00
Post-test	0.8281	0.9680	15	66.67

The p-values for both pre-test and post-test scores were greater than 0.05, indicating that the data are normally distributed and meet the assumptions for parametric statistical testing. Based on the results of the paired sample t-test, it was found that there is a statistically significant difference between the pre-test and post-test scores of students after learning with the interactive media (see Table 6). This is evidenced by the p-value of 0.0000 ( $p < 0.05$ ), indicating that the null hypothesis is rejected. In other words, the improvement in scores after the intervention is statistically significant.

**Table 6.** Paired sample t-test results

Parameter	Value
Sample size (n)	15
Mean Difference (Post-Pre)	28.67
Standard deviation of difference	8.12
t-value	13.67
Degrees of freedom	14
p-value (2-tailed)	0.0000
Cohen's d	3.53
Post Hoc Power	1 (100%)

Furthermore, the Cohen's  $d$  value of 3.53 indicates a very large effect size, according to conventional interpretation standards. This suggests that the use of inter-active media had a strong impact on students' learning outcomes.

In addition, the post hoc power value of 1 (or 100%) shows that the likelihood of the test detecting a true effect (if one exists) is extremely high. In other words, the test has excellent statistical power, indicating that the results are highly reliable and not due to random chance.

From a theoretical perspective, this improvement aligns with Kolb's Experiential Learning Theory [27], particularly the stages of active experimentation and reflective observation. The media provides students with immediate feedback, opportunities to retry incorrect answers, and explanations to consolidate their understanding. Such features support deeper cognitive processing and meaningful learning experiences, consistent with constructivist learning principles.

In addition to being effective, the interactive media was also found to be practical and user-friendly, as evidenced by the user response questionnaire. The results indicate that the media is not only functional but also well-received by students in terms of usability, content clarity, and visual design.

The findings of this study reinforce the initial concern raised in the introduction regarding students' difficulties in understanding the topic of relations and functions. As noted by previous research, more than 60% of students struggle with the abstract nature of this concept. The significant improvement in student scores after using the developed interactive media indicates that technology-based learning tools, especially those utilizing GeoGebra and contextualized with local culture, can serve as effective interventions to address this issue.

The interactive features embedded in the media—such as dynamic visualizations, immediate feedback, and contextual storylines—appear to enhance students' engagement and conceptual understanding. This supports prior claims that interactive media not only presents content but also acts as a learning facilitator. These features align with the characteristics outlined in the introduction, including responsiveness, multimedia integration, and cultural relevance, which are critical for fostering meaningful mathematics learning experiences.

The findings of this study are consistent with those of [8], who reported that GeoGebra-assisted learning significantly improved students' mathematical problem-solving skills. Similarly, [9] and [10] demonstrated that the integration of GeoGebra had a positive effect on students' mathematical achievement across various topics, both at the elementary and secondary school levels. While these studies primarily highlighted the effectiveness of GeoGebra as a visualization and problem-solving tool, the present study extends their findings by embedding GeoGebra within an interactive web-based environment supported by JavaScript, KaTeX, and Firebase. This integration enables immediate feedback, retry options, and performance tracking, thereby enhancing the level of interactivity in the learning process.

The role of interactivity has also been emphasized in previous studies. [6] found that the use of online interactive multimedia not only improved mathematics learning outcomes but also supported students' self-regulation, a critical factor for independent learning. This aligns with the present study, where interactive features—such as instant

validation of answers and opportunities for correction—were shown to engage students actively and facilitate deeper understanding. Moreover, as highlighted by [5], the integration of technological devices into mathematics education is essential for creating engaging, student-centered learning environments. In this regard, the developed media demonstrates how GeoGebra, when combined with web-based technologies, can transform mathematics learning into a more interactive, contextual, and culturally relevant experience.

However, despite the statistically significant improvement, the average post-test score (66.67) remains slightly below the minimum mastery threshold (typically 70). This highlights that while the media is effective, it may still require further refinement or additional scaffolding to ensure full mastery for all learners. This result also confirms the complexity of learning abstract mathematical topics, suggesting that a single intervention may not fully resolve deep-rooted conceptual difficulties but can serve as a strong starting point.

Moreover, the practicality of the media—evidenced by high user response scores—indicates that the integration of GeoGebra within a JavaScript-based web environment is not only pedagogically sound but also technically feasible for classroom use. These results collectively support the premise stated in the introduction: that technology, when thoughtfully integrated, can transform mathematics learning into a more engaging and student-centered process.

## 4 Conclusion and Suggestions

This study developed and validated GeoGebra-based interactive learning media contextualized with local culture to support the teaching of relations and functions. The media was found to be valid, practical, and effective, as evidenced by expert validation, high user response scores, and significant improvements in student learning outcomes. Despite the post-test average remaining slightly below the mastery threshold, the intervention demonstrated a large effect size and strong potential to enhance student engagement and conceptual understanding. These findings confirm that technology-enhanced, culturally contextualized learning tools can serve as powerful alternatives in mathematics instruction.

Future research could extend the implementation of the developed interactive media to larger and more diverse student populations, as well as across different mathematical topics beyond relations and functions. Additional scaffolding features, such as adaptive feedback and differentiated task levels, may also be integrated to address students with varying proficiency levels and ensure mastery beyond the minimum threshold. Furthermore, exploring the long-term effects of integrating GeoGebra-based media within culturally contextualized learning environments will provide deeper insights into its sustainability and impact on students' mathematical thinking.

**Acknowledgments.** The authors would like to express their sincere gratitude to the Department of Computer Education, Universitas Lambung Mangkurat, for the support and facilities provided throughout this research. Appreciation is also extended to the participating teachers and students for their valuable cooperation

**Disclosure of Interests.** The authors have no competing interests to declare that are relevant to the content of this article

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