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Design Thinking-based Adaptive Web Learning System for Science Education with Visual and Verbal Learning Modes

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Abstract

Accommodating diverse learning styles remains a challenge in science education. This pilot study used a one-group pretest–posttest design to develop and evaluate a web-based adaptive learning system for 5th grade science students at SDN Bumiayu 3 Malang (n = 27). The system assigned students to either visual or verbal instructional modes based on an initial questionnaire. Development followed the design thinking phases: empathize, define, ideate, prototype, and test. Effectiveness was measured using a 20-item multiple-choice test administered before and after a one-month intervention. The average score increased from 37.00 (SD = 9.42) to 77.33 (SD = 8.55), with an N-Gain of 0.61, indicating moderate improvement. These findings suggest that web-based adaptive systems tailored to specific learning modes can enhance students' science understanding and learning outcomes. This research provides practical insights for the broader implementation of customized digital learning tools to meet diverse student needs in similar educational settings.

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INTRODUCTION

The development of digital technology in education demands learning media that can accommodate the increasingly diverse learning needs and learning preferences of students, as each child has different learning characteristics (Asmawati, 2023; Nurdin et al., 2024; Suryawati et al., 2025). Learning can no longer use a uniform approach because students show different learning style preferences (Kazakoff et al., 2018). This shift highlights the need for educational technology not merely as a teaching aid, but as a means to offer differentiated representations and multimodal options in elementary schools (Palieraki & Koutrouba, 2021). Adopting multiple delivery strategies tailored to student characteristics has been shown to optimize learning outcomes, reinforcing the relevance of technology-based differentiation (Degeng & Triretnoningrum, 2025). Learning technology must be flexible to meet the diverse learning needs of students (Febriyana et al., 2023).

At the elementary school level, differentiation is essential because students' abilities and learning preferences are highly heterogeneous. Teachers must adopt a student-centered approach to ensure equitable access to learning for all children (Kara & Tekindur, 2025). However, manual differentiation is often difficult to apply consistently, given the high workload faced by teachers in daily classroom practice (Sellier & An, 2020). The advent of web-based learning platforms presents significant opportunities for supporting differentiation, as these platforms can provide multimodal, flexible, and interactive materials. Studies have demonstrated that e-learning environments using

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differentiated representations, such as combining text, images, animations, and simulations, effectively enhance conceptual understanding (Bouchey et al., 2021; El-Sabagh, 2021; Nouri, 2019). This approach is particularly relevant in elementary science education, where abstract topics benefit from strong visualization to support students' concrete thinking (Bouchey et al., 2021; Yulia et al., 2025). By presenting abstract scientific concepts with clear visual representations, students are better able to connect complex ideas to their real-world experiences, making learning more accessible and meaningful.

Despite these advances, many web-based learning resources in elementary education remain static, lacking adaptive features that dynamically adjust to students' needs and preferences (Ali et al., 2021). This results in less inclusive learning experiences, as students with different preferences may not receive optimal support (Al-Azawei et al., 2016). Recent developments in adaptive technologies such as natural language processing and machine learning show promise for personalizing web-based learning platforms to better support diverse learners (J. Li, 2025). These technologies enable platforms to dynamically adjust content, feedback, and learning pathways according to each student's unique needs, preferences, and progress, thereby enhancing individualized learning experiences.

The Felder–Silverman model provides a framework for understanding differences in how students prefer to engage with material. Some may process information more effectively through visual formats, others through verbal formats (Burak & Gültekin, 2021; Felder & Brent, 2024; Zagulova et al., 2019). However, it is important to acknowledge the ongoing debate regarding learning styles; current consensus suggests focusing on providing differentiated, multimodal representations to accommodate diverse learners, rather than attempting to "match" instruction to a fixed learning style. Moreover, dual coding theory supports the value of combining visual and verbal inputs to improve understanding and recall (W. Li et al., 2022). By presenting information simultaneously through both images and words, learners are able to process and store knowledge more effectively, enhancing both comprehension and memory retention.

The adaptive learning approach is becoming increasingly necessary in presenting learning materials that dynamically adjust to students' needs and preferences. This system collects user interaction data to analyze individual learning profiles, making the displayed content more personalized and relevant (El-Sabagh, 2021; Raj & Renumol, 2022). This adaptive process allows materials to change automatically, for example, through personalized content recommendations, thereby increasing the effectiveness and engagement of learning (El-Sabagh, 2021). However, the implementation of adaptive learning at the elementary school level, particularly in the context of science education, is still very limited because most research focuses on higher education or general learning environments (Raj & Renumol, 2022). Additionally, many current adaptive systems still rely on manual input, such as students filling out questionnaires to determine their learning preferences, which is often inaccurate because students don't necessarily understand their own learning styles. Therefore, the development of an adaptive system capable of automatically detecting learning preferences becomes extremely important. For example, a deep learning-based hybrid approach that combines the analysis of user interaction logs (behavioral logs) and learning style models such as FSLSM (Felder–Silverman Learning Style Model) has been shown to automatically identify learning styles and improve content personalization without relying entirely on manual input (Hussain et al., 2024). The integration of automated, data-driven adaptive learning systems, especially those leveraging deep learning to identify students' learning preferences, holds significant promise for enhancing personalization and effectiveness in elementary science education.

The design thinking approach is the right methodological choice because it focuses on empathy, exploring creative solutions, and testing based on real user experiences (Kelley & Brown, 2018). Design thinking offers a structured methodology encompassing the phases of empathize, define, ideate, prototype, and test to produce pertinent and contextually suitable educational solutions (Alvarado, 2025; Liu et al., 2024). This approach has also proven effective in digital media development because it directly involves users in the design process and enhances creativity, problem-solving, and empathy in digital learning (Blay & Espartinez, 2024; Fathullah et al., 2023). Based on research in the context of primary education, it was found that fourth- and fifth-grade students showed higher memory results when using visual strategies compared to auditory or kinesthetic strategies, indicating the effectiveness of the visual approach in improving material comprehension. Additionally,(Viet Quynh, 2024) shows that the VARK (visual, auditory, kinesthetic, and reading/writing) learning style-based teaching approach in elementary school science lessons provides more appropriate instruction and increases student interaction with the subject matter.

Web-based adaptive learning systems have proven effective in increasing student engagement and learning outcomes. The role of content personalization and material adaptation can promote optimal learning results and higher engagement in various educational contexts (Du Plooy et al., 2024). Nonetheless, the majority of research continues to concentrate on higher education and overarching learning style models, lacking a targeted focus on the integration of visual and verbal learning styles at the elementary school level. Recent experimental studies indicate that employing pure animation devoid of a presenter can markedly enhance learning outcomes by extending students' visual focus duration, which is associated with improved attention and learning results (Beautemps et al., 2025). Additionally, research in the context of mobile learning found that visual and verbal learning styles influence students' concentration and academic achievement (Lu & Yang, 2018). In blended learning in elementary school, an adaptive approach has been shown to improve reading outcomes for both English Learners (ELs) and non-Els (Kazakoff et al., 2018). Nevertheless, studies that specifically develop a web-based adaptive learning model with material adjustments based on visual and verbal learning styles for elementary school students are still very limited. Therefore, this research offers the development and testing of a web-based adaptive learning model that specifically tailors material for visual and verbal learning styles in elementary school students, an approach that remains largely unstudied empirically and systematically.

Based on these findings, this study selected 5th grade students in Malang City as the main subjects, assuming significant differences in their visual and verbal learning styles. The objective is to develop and evaluate a Web Adaptive Learning System tailored to the visual and verbal learning styles of 5th grade science students. A design thinking approach was implemented to create an adaptive web-based learning system that addresses both visual and verbal learning preferences. This system aims to support science learning in a manner that is more personalized, adaptable, and effective.

METHOD

This research uses a design thinking approach. Design thinking is a human-centered methodology grounded in empathy, collaboration, and iterative processes to comprehensively grasp user requirements and produce innovative solutions that enhance user experiences (Morris et al., 2024). The subjects of this study were 27 fifth-grade students (n=27; 11 males, 16 females; aged 10–11) at SDN Bumiayu 3 in Malang City, consisting of 17 students with visual learning styles and 10 students with verbal learning styles. Inclusion criteria required students to have parental consent to participate. Ethical approval for this research was obtained from the university's ethics committee. Written informed consent was collected from parents or guardians before data collection. All participant data were kept confidential and used strictly for research purposes. The tested product was an adaptive, web-based learning program for the sciences that included Chapter 1: Light and Its Properties and Chapter 2: Harmonious Ecosystems. The implementation was conducted over eight sessions, each lasting 60 minutes, across four weeks. The program included digital teaching modules, teacher guidance, a validated learning styles questionnaire, tailored learning content, and quizzes.

Design thinking in this study consisted of five stages: empathize, define, ideate, prototype, and test (Kelley & Brown, 2018). In the empathize stage, students' needs and challenges were explored through structured classroom observations and in-depth interviews, and the findings were visualized in an empathy map. The define stage involved synthesizing the key issues to clarify learning obstacles related to students' learning styles. The ideate stage involved brainstorming and documenting multiple solution alternatives with input from teachers and students. In the prototype stage, an initial version of the adaptive digital module was developed and iteratively refined based on user feedback, with all changes and feedback recorded in a development log. During the testing phase, all participants tried out the final prototype, and usability was measured by student satisfaction surveys and an analysis of engagement logs. Figure 1 illustrates the design thinking process.

Figure 1. Design Thinking Stages

Data were collected through observations, interviews, and questionnaires: Observations monitored student engagement, participation, and interaction with digital modules, using a structured observation protocol. Interviews were conducted with teachers and students, guided by semi-structured interview protocols. The learning styles questionnaire was adapted from Fleming & Mills' VARK model and validated through expert review (content validity index = 0.86; Cronbach's alpha = 0.81). An achievement test consisting of 20 multiple-choice questions was developed based on a content blueprint; question difficulty ranged from 0.3 to 0.7, and reliability (KR-20) was 0.78. Student satisfaction and usability were measured via a 10-item Likert-scale questionnaire with established reliability (Cronbach's alpha = 0.83). A mixed-methods approach was implemented: quantitative data (test scores, questionnaire responses) were analyzed using descriptive and inferential statistics, while qualitative data (interviews and open-ended survey items) were coded thematically. Triangulation was performed by comparing multiple data sources for consistency.

RESULTS AND DISCUSSION

The learning needs of each student are fundamentally different because individuals possess unique abilities, skills, preferences, and learning styles in understanding subject matter (Praherdhiono et al., 2025). Students with a visual learning style need representations in the form of images and diagrams, while verbal learners understand material better through narratives or educational videos. Therefore, digital media is needed that can automatically adjust content presentation according to each student's learning profile. The adaptive technology developed in this study is a Web Adaptive Learning System that presents natural science material differently based on visual and verbal learning styles.

To ensure that the developed media truly meet students' learning needs, the development process of the Adaptive Learning System in this study follows the five main stages of design thinking. These five stages not only serve as a systematic workflow but also as a reflective framework for deeply understanding user experiences and making iterative improvements. The design thinking stages implemented in the development of this system include empathize, define, ideate, prototype, and test, which are explained as follows.

Empathize

At the empathize stage, the researcher gathered in-depth information about the needs, experiences, perceptions, and learning barriers of 27 fifth-grade students and 1 teacher at SDN Bumiayu 3 in Malang City. The main focus was to understand how students process science material, their preferences for content presentation, and the constraints they face with previous learning media. Data were collected through classroom observations, informal interviews with students and the teacher, and a simple questionnaire to identify visual and verbal learning style tendencies.

Qualitative data analysis was conducted using thematic coding. Every student and teacher response was grouped by theme, and the frequency of each was counted. Based on the questionnaire adapted from Burak & Gültekin, 17 students (63%) had a visual learning tendency, and 10 students (37%) were verbal learners. Twelve visual learners stated, "I understand better when there are pictures or animations" (verbatim). Nine students (a mix of visual and verbal) said, "I sometimes get bored just reading text." Additionally, some verbal learners (n=6) shared, "If there is a video or audio explanation, I understand faster." The classroom teacher also noted, "Students tend to be passive if using only text-based PPTs," based on direct observation.

The initial media provided was a prototype of the Web Adaptive Learning System, consisting of 5th grade science material, specifically the topics "Light and Its Properties" and "Harmonious Ecosystems," presented in two modes. Visual mode loads images, diagrams, illustrations, and short text summaries, while verbal mode loads educational videos, explanatory narratives, and supporting audio. Each material is equipped with interactive quizzes that can be completed directly through the web. Student interaction with this prototype was observed to understand initial responses and usage preferences. During prototype use, several students stated, "I want to choose the one with lots of pictures," while others said, "I think I understand better when there's more explanation." Observations showed that visual learners more frequently chose the illustration-rich mode, while verbal learners were more engaged when audio/video explanations were available.

The empathize stage aimed to directly explore students' thoughts, desires, needs, and learning experiences. All feedback and quotes from students and the teacher were analyzed and validated through researcher discussions to ensure consistency of interpretation (inter-rater reliability) and triangulated with classroom observations. The resulting Empathy Map (see Figure 2) concisely summarizes what students think and feel (e.g., "I'm afraid I won't understand the material if I just read the book" [6 verbal learners]), what they see (e.g., web interface changes, illustrations, assignment notifications), hear (e.g., teacher/parent instructions), say and do (e.g., asking the teacher for help or discussing features with friends), as well as pains (e.g., "Visual content can be confusing for verbal learners" [3 verbal learners]) and gains (e.g., "Material is easier to understand when presented according to my learning style," stated by 15 students).

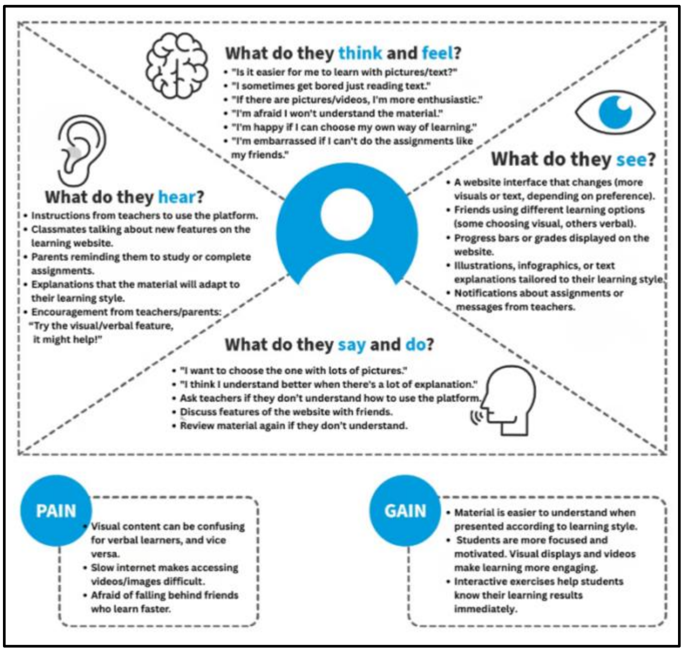

Figure 2. Empathy Map

The empathy map illustrates a comprehensive understanding of students' experiences while using an educational platform. It highlights what students think and feel, such as their preferences for visual or text-based content and concerns about understanding material. The map also shows what students see, including customizable interfaces, friends using different learning options, and visual progress indicators, as well as what they hear from teachers, parents, and classmates about assignments and platform features.

Based on the responses from students and teachers during the empathize stage, the researcher conducted an in-depth analysis of all the input provided. We record each piece of feedback and use it as a basis to formulate the core issues for the next stage. This process is carried out to ensure that the developed solution is truly relevant, comprehensive, and effective for real users, as (Liu et al., 2024) stated that empathetic understanding is the main foundation for developing design thinking-based solutions.

Define

In the define stage, the researcher formulated the core problems strictly based on the data and insights gathered during the empathize process. Information from classroom observations, interviews, and the learning style questionnaire was systematically coded and analyzed. 12 out of 17 visual learners (70.6%) reported difficulties when presented with lengthy text and few illustrations, as captured in the quote, "I understand better when there are pictures or animations." Meanwhile, 6 out of 10 verbal learners (60%) felt less supported by predominantly visual materials, stating, "If there is no audio explanation, I find it hard to follow." The teacher also confirmed these issues, remarking, "It is difficult to consistently create both visual and verbal versions of each material, and it takes a lot of time."

Therefore, the core problem statements defined at this stage are as follows:

a. A majority of students require science materials presented in formats that match their learning styles to optimize their understanding.
b. There is a lack of integrated multimodal resources in current science instruction, limiting engagement and conceptual learning.
c. Teachers need digital tools that can efficiently and automatically differentiate instruction to accommodate student diversity without increasing their workload.

This clear, data-driven problem definition ensures that subsequent solution development in the "ideate" and "prototype" stages is targeted, relevant, and evidence-based, consistent with best practices in design thinking. This result aligns with the view that the define stage should focus on defining the core user needs to ensure the developed solution is targeted (Dam & Siang, 2020). Previous research confirms that accurately identifying user needs is a critical step to ensure that the educational products developed are truly relevant and capable of addressing existing learning problems (Li & Zhan, 2022; Liedtka, 2015). By thoroughly understanding what learners require, developers can design solutions that are better aligned with real-world challenges and more likely to produce meaningful educational outcomes.

The obtained data indicate that visual learners encounter difficulties when presented with long text and minimal illustrations. This condition is consistent with the Felder-Silverman learning styles concept, which states that visual learners consider it easier to understand information through images or nonverbal representations (Burak & Gültekin, 2021). Conversely, verbal learners feel less supported when the material presented is predominantly visual without narrative or verbal explanation. This aligns with the dual coding theory, which explains that verbal and visual processing occur through two different channels, so modality mismatch can reduce learning effectiveness (W. Li et al., 2022). Therefore, ensuring that visual and verbal information are presented in a complementary and coordinated manner is essential for optimizing students' comprehension and retention.

Besides the needs of the students, the teachers also shared the challenges they face in preparing materials that cater to diverse learning preferences. The teacher stated that creating two versions of visual and verbal media takes a lot of time and is not easy to do consistently. Recent research confirms that teachers often experience a high workload when they have to differentiate instruction without adaptive technology support (Yuen et al., 2023). In the digital context, teachers need a system that can automate differentiation so that learning remains adaptive without burdening the planning process. A recent experimental study also showed that automated or semi-automated scenarios in digital content recommendation systems significantly reduced teachers' perceived workload compared to a manual approach(Machado et al., 2025). This suggests that integrating automation into educational technology can help streamline teachers' tasks, allowing them to focus more on instructional activities rather than administrative or repetitive work.

The researchers developed an adaptive system to solve three main problems based on these findings. First, students need science materials presented in a way that suits their learning styles so that concept understanding can be more optimal. Second, the presentation of learning materials needs to incorporate rich multimodal representations with illustrations, diagrams, narratives, and videos, aligning with the finding that multimodal learning significantly supports conceptual understanding and student engagement in contemporary STEM education contexts (Bouchey et al., 2021). Third, teachers need digital media that can automatically differentiate so they don't have to manually prepare materials for each learning style. This approach is supported by recent studies on the use of adaptive learning platforms and differentiated instruction, which have shown effectiveness in presenting personalized content tailored to students' needs (Herliana et al., 2024). This problem formulation is also in line with the principle that the define stage must produce a clear understanding of the core challenges before solutions are developed in the design of adaptive learning systems (Bewersdorff et al., 2025). Clarifying the main issues at the outset ensures that subsequent design efforts are focused, relevant, and more likely to yield effective and targeted educational solutions.

Ideate

During the ideation phase, researchers, teachers, and student representatives conducted brainstorming sessions to generate various alternative solutions for adaptive science learning. The ideation process was carried out through focus group discussions involving two classroom teachers, four students (two visual, two verbal), and the researchers. Some alternative solutions generated include (1) interactive animated videos, (2) digital learning modules with visual/verbal mode customization features, (3) educational game-based mobile applications, and (4) adaptive websites that automatically adjust the display according to students' learning styles. Each alternative was analyzed based on ease of implementation, the school's technological capabilities, and its potential to increase student motivation and understanding.

Based on discussion and voting, the majority of participants (teachers and students, 5 out of 7 votes) chose an adaptive website as the primary solution because it was considered the easiest to access, could be operated on available school devices, and could automatically accommodate the needs of both visual and verbal learners. This decision is also supported by considerations of teacher time efficiency and ease of material management, ensuring that the chosen solution truly addresses the main problems identified in the define stage. Based on the chosen solution, Figure 3 shows the flowchart design for Adaptive web-based learning.

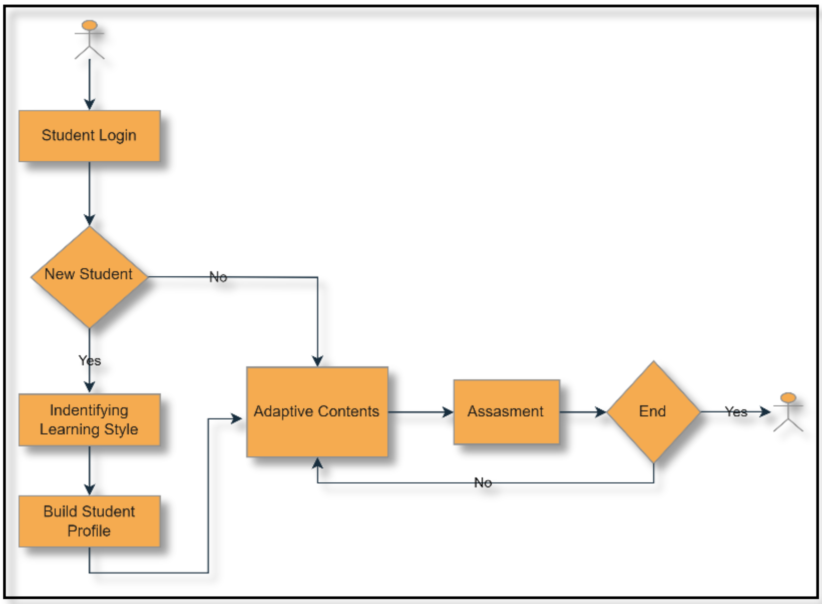

Figure 3. Design Adaptive Web Learning

The flowchart for the Adaptive Web-Based Learning system begins with students logging into the platform. Once logged in, the system checks whether the user is a new student. If the user is new, the system identifies the student's learning style through a series of questions or assessments and then builds a personalized student profile. Based on this profile, the system delivers adaptive learning content tailored to the student's individual needs and learning preferences. After engaging with the learning materials, the student completes an assessment to evaluate their understanding. If the learning process is complete, the flow ends; otherwise, the student can revisit the adaptive content as needed. This process ensures that each student receives a personalized and effective learning experience.

The learning system developed in the Web Adaptive Learning System contains several sub-materials or learning units. Each unit contains visual or verbal materials tailored to students' learning profiles (El-Sabagh, 2021; Du Plooy et al., 2024), examples of scientific phenomena, interactive quizzes, and brief explanations to reinforce concept understanding. Visual mode provides content in the form of images, diagrams, concept illustrations, simple infographics, and material summaries in short, structured text (Bouchey et al., 2021). Meanwhile, verbal mode offers learning videos, explanatory narratives, storytelling, and more descriptive explanatory text (Lu & Yang, 2018; Burak & Gültekin, 2021).

Each unit is equipped with simple navigation to make it easier for students to access the material, thus reducing confusion. Dividing the material into several units also aims to minimize cognitive load and provide students with the flexibility to learn at their own pace (Li et al., 2022). The use of a web platform was chosen because it offers high flexibility and easy accessibility through both laptops and mobile devices, and supports the development of multimodal features that are not possible on static media like PowerPoint (Praherdhiono et al., 2025; Nurdin et al., 2024).

As part of the learning evaluation, the system also provides interactive quizzes that can be accessed after students complete the material. These quizzes are designed without differentiating between visual and verbal learning styles, ensuring all students take the same form of evaluation. The implementation of interactive quizzes aims to increase student engagement through a more appealing presentation while also providing a more varied evaluation experience compared to conventional questions. This interactive quiz feature also allows students to monitor their understanding of the material in real-time and receive immediate feedback on their answers. Additionally, teachers can utilize quiz result data to gain insight into students' concept mastery levels and take follow-up learning actions if necessary.

Overall, this ideation phase resulted in the initial design of the key features that will be implemented in the Adaptive Learning System Web prototype. All generated ideas were carefully selected, adapted, and combined to ensure the system truly met the learning needs of fifth-grade students and addressed the identified science learning barriers from the previous stage.

Prototype

After a series of ideas were developed in the ideation phase, the next step was to build an initial prototype of the Web Adaptive Learning System, designed to adapt the presentation of science material to visual and verbal learning styles. This prototype serves as an initial representation, allowing researchers to evaluate the design's suitability for the real needs of 5th grade students. This stage is crucial for understanding student responses to the system design before it is further developed into the final product.

The prototype represents the prototypical phase in design thinking. Prototypes are used to determine how users behave with the product results that have been made by finding solutions through the previous stages. Two strategies are used in prototype development: the creation of low-fidelity and high-fidelity prototypes. Low- fidelity is the simplest design, while high-fidelity is the most final design that is used for testing with users (test stage) (Bianchi & Elia, 2022). In this study, the low-fidelity prototype will be used for initial trials. This initial testing aims to gather feedback and suggestions for improvement. Based on the input obtained from this stage, revisions will be made before developing the high-fidelity prototype. The high-fidelity prototype will then be tested in the next phase with the entire class, ensuring that the design has been optimized according to the feedback from the initial trial.

Low-Fidelity Prototype and Initial Trial

The low-fidelity prototype was created as a basic design focusing on layout and core features. This version was tested with 8 students (4 visual, 4 verbal) to identify usability issues, clarity of instructions, and gather initial user suggestions. The main solution generated at the ideation stage is the provision of two modes of material presentation designed according to students' learning style preferences (visual and verbal mode). Visual mode contains images, diagrams, concept illustrations, simple infographics, and material summaries in the form of short, structured text. Figure 4 explains the display of the visual mode in an interactive learning platform. The figure shows an example of a learning module interface for Sciences with the topic "Light and Its Properties". The interface uses visual elements such as drawings of a flashlight, a mirror, and a light bulb to illustrate the concept. Additionally, the checklist above the module indicates certain access conditions, such as availability only for users who belong to the Visual group.

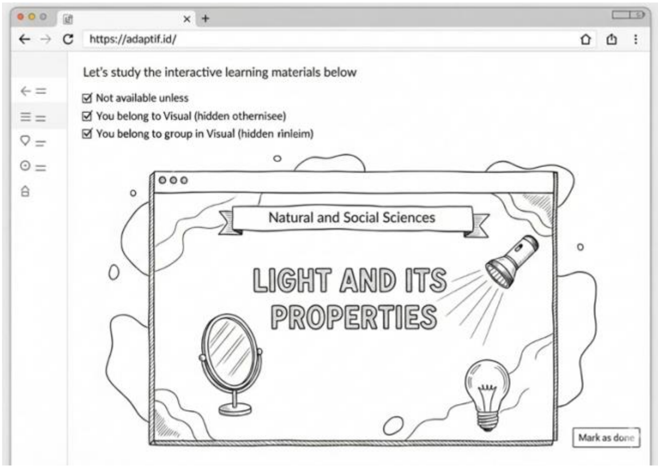

Figure 4. Visual Mode Display Low-Fidelity Prototype

The verbal mode contains learning videos, explanatory narration, storytelling, and more descriptive explanatory text. Figure 5 explains the display of the verbal mode in a web-based adaptive learning system. This mode provides users with learning materials in the form of videos, narrations, and descriptive explanations. The figure demonstrates that the content for "Analyzing and Evaluating the Problem-Solving Process" is only available to users categorized in the verbal group. If a user belongs to the verbal group, they can access a learning video presented by Kak Arief on the topic "*Sound and Nature*." This setup supports learners who benefit from verbal explanations and storytelling.

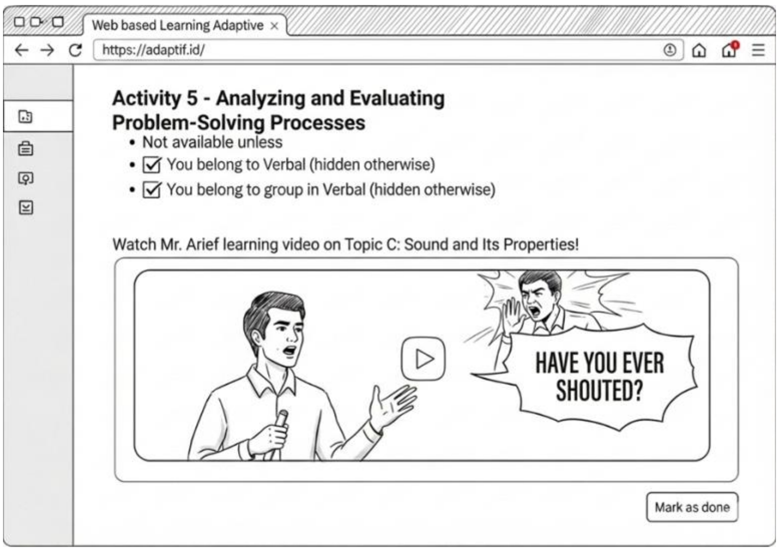

Figure 5. Verbal Mode Display Low-Fidelity Prototype

During these trials, visual learners suggested simplifying navigation and adding clearer images, while verbal learners requested audio narration in each subtopic. The teacher provided valuable suggestions, recommending the addition of animated videos to help clarify abstract science concepts. Furthermore, the teacher proposed integrating augmented reality (AR) technology, so students could experience interactive and immersive learning, such as viewing 3D models of science concepts.

High-Fidelity Prototype

Based on feedback from the low-fidelity trial, the prototype was revised and developed into a high-fidelity version with enhanced visuals, comprehensive interactive features, and audio narration for verbal content. Animated videos were added to key subtopics as recommended by the teacher. Additionally, the development team began integrating basic AR features for certain materials, such as simulations of light and ecosystems. Navigation was streamlined, and buttons were enlarged for better accessibility. An automatic quiz feedback feature was also added, following teacher feedback. Figure 6 provides a summary of the unique properties of light in a way that is easy to understand for visual learners. The use of icons and numbered points makes the material more engaging and helps students quickly grasp the key concepts about light without lengthy explanations. This aligns well with the visual mode prototype's goal to deliver educational content through images, diagrams, the use of augmented reality, and concise text for better comprehension.

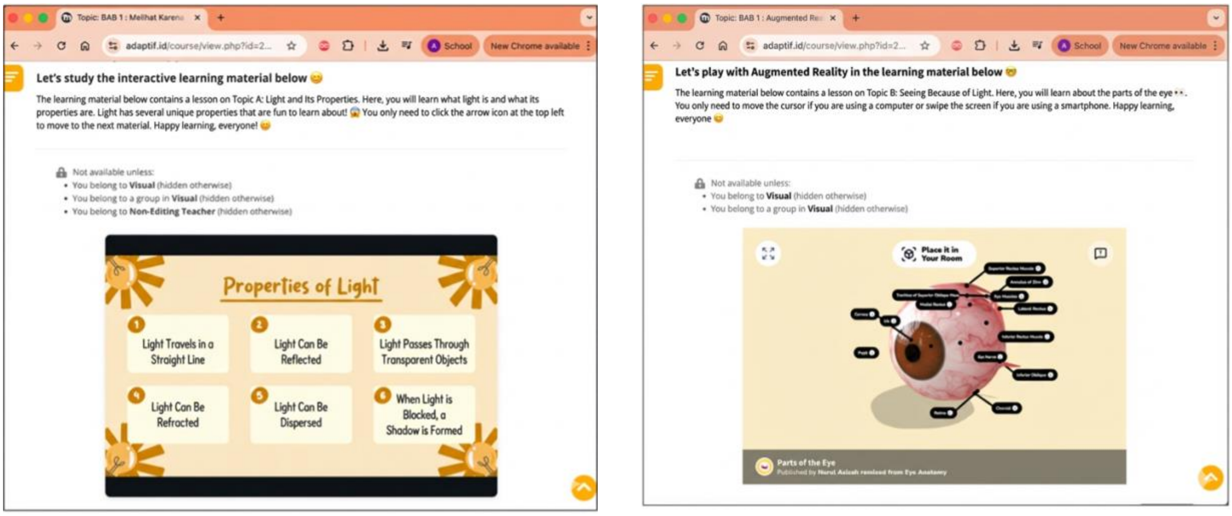

Figure 6. Visual Mode Display Prototype High-Fidelity

Prototipe Mode Verbal

Verbal Mode Prototype In the verbal mode prototype, the material is presented through learning videos, explanatory narratives, and short storytelling about science phenomena. Figure 7 explains the display of the Verbal Mode Prototype in a digital learning environment. In this prototype, learning content is delivered through a video featuring a presenter (Kak Intan) who explains scientific concepts, in this case, the topic of "Sound and Nature." The learning videos and animated videos format utilizes spoken explanations and short narratives, making it suitable for learners who prefer verbal or auditory instruction. The screenshot also shows a combination of real-life presenters and animated illustrations to enhance understanding and engagement. This approach aims to strengthen students' comprehension by presenting information in a clear, narrative, and interactive way, characteristic of the verbal learning mode.

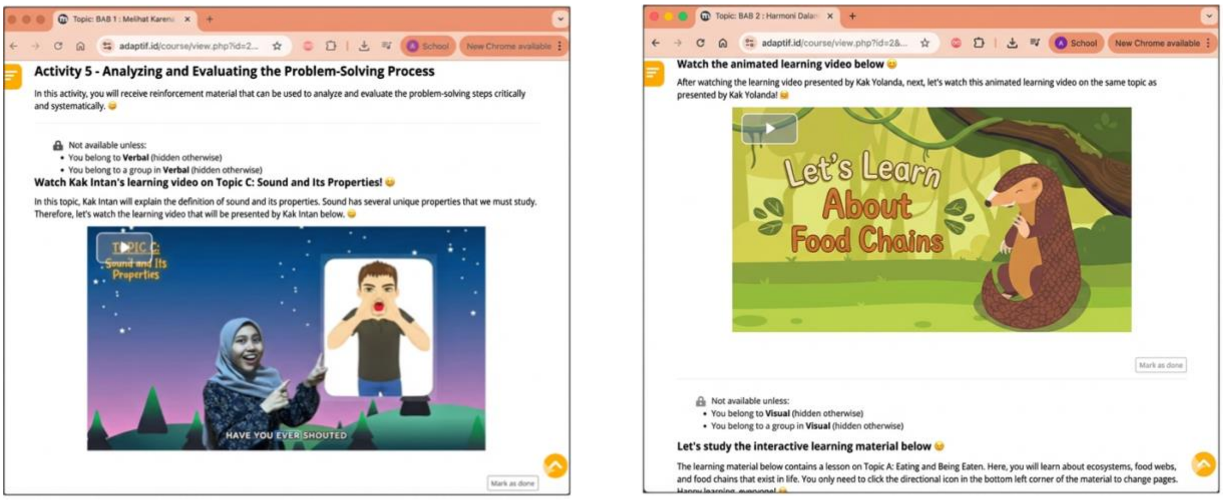

Figure 7. Verbal Mode Display Prototype High-Fidelity

This prototyping stage provides an initial overview of how the visual-verbal adaptive learning system works and how students respond to these two types of material presentation. Input and observations from students are an important basis for system refinement before moving to the next stage, which is testing, within the Design Thinking framework. This visual presentation emphasizes the structure, readability, and clarity of the representation so that visual learners can understand scientific phenomena through graphical representations. In the initial trials, some students reported that the image size on the first screen was still too small when accessed via mobile phones. Based on this feedback, the prototype's appearance was then revised by increasing the proportion of images, adjusting color contrast, and simplifying the layout to make it easier to scan.

The videos in the verbal mode prototype are structured with a short duration and step-by-step explanations to make them easy to understand and not burden students' devices when accessed through the school network. Initial student feedback indicates that some videos are considered too dense in a single view. To address this, the prototype was updated by dividing the video into several short segments and inserting supporting narrative text so that verbal learners could receive explanations step by step. This aligns with the statement by Ulfa et al. (2019) that A personalized learning process requires an adaptive learning system (ALS). To adapt, a learner model is required, which emphasizes the importance of developing an adaptive system based on a learner model as the foundation for a personalized learning process.

The high-fidelity prototype was then tested with the entire fifth-grade class (n = 27) over eight sessions to evaluate usability (using a structured questionnaire), student engagement, and learning effectiveness. Results showed a high usability score (SUS mean = 82.5; SD = 6.1), and the majority of students (24 out of 27, or 89%) reported being satisfied with both the ease of use and the media's appearance. The teacher noted that the addition of animated videos and AR features had significant potential to improve student understanding and motivation.

Test

The testing phase is the final step in the design thinking process, aiming to evaluate whether the adaptive learning system web prototype meets user needs and has an impact on improving learning outcomes (Kelley & Brown, 2018; Alvarado, 2025). At this stage, fifth-grade students at SDN Bumiayu 3 used the adaptive system to learn the materials "Light and Its Properties" and "Harmonious Ecosystems." Evaluation was conducted through observation, questionnaires, brief interviews, and learning outcome tests in the form of pretests and posttests (Dam & Siang, 2020; Li & Zhan, 2022). The pretest and posttest consisted of 20 multiple-choice items designed to objectively measure students' understanding before and after using the system.

A total of 27 students participated in the testing. The pretest mean score was 37.00 (SD = 8.15, n = 27), and the posttest mean score increased to 77.33 (SD = 7.95, n = 27). The N-Gain value calculated was 0.61 (moderate category), indicating a substantial improvement in learning outcomes. A paired t-test revealed that this improvement was statistically significant ($t = 15.2$, $p < 0.001$), with a large effect size (Cohen's $d = 2.5$). Usability was measured using the System Usability Scale (SUS), resulting in a mean score of 82.5 ($SD = 6.1$), with 24 out of 27 students (89%) reporting satisfaction with the platform's ease of use and features.

Qualitatively, students expressed high enthusiasm for using this system. Visual learners stated that illustrations and images helped them understand abstract science concepts, although several suggested increasing image size, especially on mobile devices (Burak & Gültekin, 2021; Lu & Yang, 2018). Verbal learners responded positively to video presentations, but some recommended slowing down narration speed or splitting videos for easier comprehension (Li et al., 2022; Beautemps et al., 2025). The fifth-grade teacher observed that students were more focused, better directed, and understood the material faster when using the adaptive system compared to conventional PPT media. Additionally, both students and the teacher noted that the inclusion of animated videos and AR features further enhanced engagement and understanding. Here's a summary of the pretest, posttest, and N-Gain scores for the class in Table 1.

Table 1. Summary of Pretest–Posttest Learning Outcomes and N-Gain

Group	n	Pretest Mean (SD)	Posttest Mean (SD)	N-Gain
All students	27	37.00 (8.15)	77.33 (7.95)	0.61
Visual learners	17	36.2 (8.0)	76.8 (7.9)	0.60
Verbal learners	10	38.5 (8.4)	78.4 (8.2)	0.63

These results indicate that the Adaptive Web Learning System is effective in improving the understanding of fifth-grade science concepts for both visual and verbal learners. The integration of multimodal content, animated videos, and AR, combined with high usability, contributed significantly to learning gains and positive user experiences (Bouchey et al., 2021; Beautemps et al., 2025; Bewersdorff et al., 2025). These findings show that not only did students and teachers respond positively to the adaptive system prototype, but it also significantly enhanced learning outcomes. Presenting material tailored to visual and verbal learning styles provides a more personal, meaningful, and relevant learning experience for elementary school students (Lu & Yang, 2018; Burak & Gültekin, 2021; Viet Quynh, 2024). Overall, this adaptive system proved to be feasible. Differences in learning styles have a real impact on learning outcomes, making adaptive learning important (Zagulova et al., 2019). The study by Degeng & Triretnoningrum (2025) also showed synergy between technology-based media and learning style preferences for improved academic outcomes. Additionally, Adi et al. (2024) reinforce the importance of developing and utilizing digital media that are responsive to the diverse learning needs of students.

These results contribute to the broader field of education, especially online learning, by highlighting the value of adaptive systems in creating more inclusive and effective digital learning environments. In the context of online education, where addressing individual student needs can be challenging, adaptive technology offers a practical solution by personalizing instruction and content delivery. This not only enhances learning outcomes but also fosters higher engagement and motivation among students. Therefore, this research underscores the importance of integrating adaptability and personalization into digital learning platforms, paving the way for more equitable and accessible educational experiences for all learners.

LIMITATIONS

This study has several limitations. The adaptive learning system developed and tested only involved 5th-grade students in Malang City, thus limiting the generalizability of the findings. Additionally, the system is only adapted to visual and verbal learning styles, without considering others. Data collection also relies entirely on self-reports from students, which could introduce subjectivity. Further research is suggested to involve a more diverse range of participants and expand the scope of learning styles accommodated.

CONCLUSION

The application of design thinking in the development of an adaptive web-based learning system for 5th-grade science subjects has proven effective in improving student understanding. The system development process follows the design thinking stages, namely empathize, define, ideate, prototype, and test. This system provides visual and verbal learning modes that are suitable for students' learning styles. The evaluation results show an increase in the average score from 37 to 77.33 with an N-Gain value of 0.61 (effective category). Thus, this system is able to provide a more personalized and interactive science learning experience. However, the ease of understanding the usage instructions still needs to be improved to optimize the effectiveness of the media. Further research is suggested to develop more diverse customization features and conduct trials at other grade levels and subjects to broaden the benefits of this adaptive learning system.

AUTHOR CONTRIBUTIONS

All authors contributed significantly to this research. ARH is responsible for research design, developing an adaptive learning system based on design thinking, and writing the initial draft of the article. INSD plays a role in data collection, data analysis, and the implementation of system evaluations on the research subjects. WK contributed to the validation of the research instrument and supervised the design thinking methodology used. YS provided academic supervision, conducted a critical review of the manuscript, and contributed to the improvement of the article's content and writing style. All authors have read and approved the final submitted manuscript.

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