

DEVELOPMENT OF BIODIVERSITY LITERACY BASED VIRTUAL REALITY MEDIA TO IMPROVE STUDENTS CONCEPTUAL UNDERSTANDING AND CRITICAL THINKING SKILLS

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ABSTRACT

This study aims to develop a valid, practical, and effective biodiversity literacy-based Virtual Reality learning medium to improve tenth-grade students' conceptual understanding and critical thinking skills at SMK Negeri 1 Paguyaman. The Virtual Reality medium brings the local ecosystem of the Nantu Wildlife Reserve into the classroom, overcoming field observation constraints regarding access, cost, and time. Using the ADDIE research and development (R&D) model, the product was validated by three experts (content, test-item, and media). It was tested through limited (20 students) and main (50 students) trials across three meetings in the IPAS Project subject. Data were collected via validation sheets, observation sheets, student response questionnaires, and pre/post-tests, then analyzed using percentages and N-Gain. Results showed the media was valid to very valid. Practicality was rated as very practical, supported by 100% positive student responses. Improvements in conceptual understanding (N-Gain = 0.47-0.68) and critical thinking skills (N-Gain = 0.54-0.61) fell into the medium category. Thus, the developed Virtual Reality medium is valid, practical, and effective for classroom instruction.

Keywords: virtual reality; biodiversity literacy; concept understanding; critical thinking skills

INTRODUCTION

Biodiversity plays a crucial role in maintaining ecosystem balance and providing natural resources that sustain human life. Biodiversity literacy education serves as an essential instrument to equip students with the knowledge and skills to understand and appreciate biodiversity in their environment (Opel & Bogner, 2020). Through robust biodiversity literacy, students are expected to comprehend the complex interactions between organisms and their environment (Putri dkk., 2023). This understanding develops into comprehensive conceptual mastery rather than rote memorization, serving as a foundation for critical thinking skills so that students possess the analytical sharpness to solve environmental

challenges and make responsible decisions for the sustainability of local ecosystems (Xu et al., 2023).

The reality in the field reveals a concerning gap. The biodiversity literacy of students at SMK Negeri 1 Paguyaman is categorized as low, marked by a minimal introduction to local biological wealth; endemic plants and animals are perceived as more unfamiliar compared to information from external media. This condition is exacerbated by low critical thinking skills, which are compounded by low national reading interest (Pitri & Sofia, 2022). Low literacy makes it difficult for students to process complex scientific information regarding ecosystems, trapping them in rote learning

patterns and thus failing to analyze the interconnectedness of information among environmental components, as well as lacking the ability to propose constructive ideas for environmental problems in their region (Annisa et al., 2021). In fact, critical thinking is one of the core competencies of 21st-century skills (Jannah et al., 2025). This condition demands media capable of presenting ecosystems as explorable experiences rather than mere memorization material. Immersive learning based on Virtual Reality is highly relevant to this need. According to the Cognitive Affective Model of Immersive Learning (CAMIL), the advantages of Virtual Reality stem from two primary affordances: presence (the feeling of being inside a virtual environment) and agency (control over one's actions within it). Both influence affective and cognitive factors such as interest, motivation, self-efficacy, embodiment, cognitive load, and self-regulation, which in turn determine learning outcomes (Makransky & Petersen, 2021). Regarding conceptual understanding, a contextual virtual environment allows students to interpret, exemplify, and classify ecosystem components directly within their context, thereby supporting meaningful processing over rote learning. Findings by Baceviciute et al. (2021) align with this, showing that environmental embeddedness in Virtual Reality yields better knowledge transfer performance, despite requiring higher cognitive effort. For critical thinking skills, the opportunity to directly observe, compare, and trace interrelationships among components provides a practice space for indicators such as interpretation, analysis, evaluation, and inference. Systematic reviews also demonstrate that

Virtual Reality contributes to the development of critical competencies beyond mere knowledge transfer (Cabrera-Duffaut et al., 2024).

Learning is also hindered by the limitations of conventional media in visualizing ecosystems concretely, as well as by constraints in cost, time, procedures, and difficult terrain that make direct observation in natural habitats challenging. Meanwhile, vocational high school (SMK) students, who belong to Generation Z, tend to prefer practical-visual learning over lectures (Bamberger, 2006). The construction of student knowledge needs to involve mind-on and heart-on aspects so that conceptual understanding does not stop at memorization (Hasan et al., 2017), thus demanding teachers to act as innovators capable of creating quality and sustainable learning (Dama, 2021). Given the importance of conceptual understanding in science learning, students' ability to comprehend scientific concepts still requires enhancement (Larasati et al., 2025).

Virtual Reality offers a solution to these spatial and temporal limitations through three main affordances. First, it provides an immersive learning experience through multi-sensory stimulation (Al-Gindy et al., 2020). Second, it allows students to explore locations that are physically difficult to reach (Nayyar et al., 2018). Third, it can transform abstract concepts into tangible three-dimensional visualizations (Fernanda et al., 2024) and be utilized to train decision-making through environmental change simulations (Shepherd, 2019; Ou et al., 2021).

Previous studies have shown that Virtual Reality can improve learning outcomes (Dewi, 2020; Firmansyah, 2025), the retention of concept

understanding (Abdussalam et al., 2018), and critical thinking skills (Adawiyah et al., 2025). However, the development of Virtual Reality generally still employs general, global content and has yet to address local ecosystems relevant to the students' living environment. Such content is also rarely designed around the characteristics of vocational education.

To address this gap, this study uses biodiversity literacy as the conceptual and content foundation for designing the Virtual Reality media. Biodiversity literacy is generally understood as encompassing knowledge, awareness or attitudes, and action regarding biodiversity, although its conceptualization varies among researchers (Aminullah et al., 2025). Within this framework, the knowledge dimension includes understanding of species, ecological relationships among living things, and conservation issues (Aminullah et al., 2025). Biodiversity literacy remains a concern among secondary school students (Aslan Efe & Efe, 2022), and conservation-oriented education has been

proposed as a strategy to strengthen it (Fajri et al., 2025). Accordingly, the framework guided the selection and organization of the media content, namely the biotic and abiotic components, species, and ecosystem of the Nantu Wildlife Reserve, as well as environmental problems in the students' region. Biodiversity literacy thus serves as a design foundation rather than an outcome variable. The learning outcomes measured were limited to concept understanding and critical thinking skills, which are the cognitive competencies this content is intended to develop.

The novelty of this research lies in the integration of local content-based biodiversity literacy of the Nantu Wildlife Reserve into Virtual Reality media designed for vocational education characteristics. This study aims to develop a valid, practical, and effective biodiversity literacy-based Virtual Reality media to enhance concept understanding and critical thinking skills of tenth-grade students at SMK Negeri 1 Paguyaman.

METHOD

This study is a Research and Development (R&D) project (Sugiyono, 2019) utilizing the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) (Branch, 2010). Product quality is evaluated based on three characteristics: validity, practicality, and effectiveness (Nieveen, 1999). The research was conducted at SMK Negeri 1 Paguyaman during the 2025/2026 academic year within tenth-grade IPAS Project learning, focusing on the local ecosystem content of the Nantu Wildlife Reserve.

The development process of this media was carried out using the ADDIE model, which consists of five main phases. The analysis phase began with observations of *Projek IPAS* learning and interviews with 10th-grade teachers to examine learning problems, infrastructure and facilities, internet network access, student characteristics, device availability, materials aligned with *Kurikulum Merdeka*, and learning outcomes. The interviews focused on a single school context and a narrow objective; thus, a limited number of informants was deemed sufficient. This aligns with a systematic

review showing that thematic saturation is generally reached within the range of 9–17 interviews for a relatively homogeneous population with a narrowly defined purpose (Hennink & Kaiser, 2022). Subsequently, the design phase encompassed formulating learning objectives, designing storyboards and interface layouts, selecting audio-visual elements such as illustrations, animations, colors, sound effects, music, and narration, as well as developing evaluation instruments.

The development phase encompasses the production of the media along with its supporting elements (images, videos, audio, and information regarding the Nantu Wildlife Reserve ecosystem), validation by two subject matter and assessment experts as well as one media expert, and revisions based on the validators' feedback. The developed Virtual Reality media operates at a medium immersion level, utilizing Android smartphones aided by dedicated Head-Mounted Displays (HMD) with modeled 3D environments, enabling students to experience a visual and auditory sense of presence within the wildlife reserve. Within the CAMIL framework, the level of immersion determines the intensity of presence, whereas interactivity dictates agency, both exerting separate and combined effects on students' cognitive and affective processes (Makransky & Petersen, 2021). Students interact with the virtual environment by looking around, exploring, and selecting informational hotspots via gaze or button inputs. This form of interaction is classified as medium interactivity, as students determine the sequence of exploration without manipulating virtual objects. Usage is restricted to four scenes

across three sessions. Limiting the duration is crucial because high immersion levels have the potential to increase extraneous processing load (Albus et al., 2021) and induce discomfort in some users. These were then validated by two subject matter and assessment experts and one media expert, followed by revisions based on the validators' feedback. The evaluation phase itself was conducted continuously throughout the development process to maintain both technical and content quality.

The implementation phase was carried out through a small-group trial and a field trial. In both phases, learning took place across three sessions, with a time allocation of 4 credit hours (4 X 45 minutes) per session, directly observed by two observers who were *Projek IPAS* teachers. The media's effectiveness was measured using a one-group pretest–posttest design in each session. Trial subjects were selected purposively because developmental research requires criteria matching the product's target, namely 10th-grade students enrolled in the *Projek IPAS* course. As a non-probability sampling technique was used without statistical power calculations, the research findings are generalized cautiously strictly to the sample subpopulation, with the sample size justified transparently based on resource constraints such as device availability, time, and accessible class populations (Lakens, 2022).

The small-group trial involved 20 10th-grade students selected from Class X TM, ATU, APHP, representing a variation in students' initial abilities (high, moderate, and low) based on teacher recommendations. This sample size was established to evaluate readability, instructional feasibility, and technical

constraints of the media within a small group. Meanwhile, the field trial involved 50 students from three vocational programs divided into two study groups: Class X AKL and a combined group of Class X APHP and Class X ATPH. Selecting these three classes aimed to provide diversity in vocational specialization backgrounds. Overall, the trial participants were 10th-grade vocational high school (SMK) students

aged approximately 15–16 years. Most students owned personal mobile devices with internet access, but had no prior experience using Virtual Reality based media in the learning process. A pretest and posttest were administered at each meeting using a one-group pretest–posttest design (Table 1).

Table 1. Subjects and Trial Design

Stage	Subjects	Design	Seasion	Observers
Limited trial	20 tenth-grade students	One-group pretest–posttest (O1 X O2)	4 × 5 JP (45 minutes)	2 IPAS Project teachers
Broad trial	50 tenth-grade students (X AKL; combined X APHP and X ATPH)	One-group pretest–posttest (O1 X O2)	4 × 5 JP (45 minutes)	2 IPAS Project teachers

Validity was assessed using material, media, and test-item validation sheets employing a 1–5 Likert scale. The material aspect covered alignment with learning objectives, presentation quality, material suitability, supporting materials, accurate information, and development attitude; the media aspect covered visual design, audio, video, animation, ease of use, and impact on user attitude; while the test-item aspect covered alignment with learning objectives, construction, as well as language and sentence structure.

Practicality was measured through teacher implementation observation sheets, student activity observation sheets, and student response questionnaires consisting of 20 positive and negative statements. Effectiveness was measured using a concept-understanding test comprising 7 multiple-choice questions referring to the cognitive process dimensions of Anderson and Krathwohl (2017) namely interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining—as

well as a critical thinking skills test comprising 6 higher-order thinking skill-based multiple-choice questions referring to Facione's (2015) indicators, namely interpretation, analysis, evaluation, inference, explanation, and self-regulation. The validation data were analyzed using the following percentage formula and converted into categories as shown in Table 2 (Hartini et al., 2018):

$$P = (\Sigma x / \Sigma xi) \times 100\%$$

The observation data on learning implementation and student activity were analyzed quantitatively and descriptively as the percentage of the score obtained against the total score, then converted using Widoyoko's (2016) criteria (Table 2). Student responses were calculated as a percentage for each answer category. Effectiveness was explained using the Normalized Gain (N-Gain) with the categories presented in Table 3 (Meltzer, 2002):

$$\text{N-Gain} = (\text{Skor posttest} - \text{Skor pretest}) / (\text{Skor ideal} - \text{Skor pretest})$$

Tabel 2. Criteria for Assessing Validity, Learning Implementation, and Student Activity

Score Interval (%)	Validity Category	Implementation and Student Activity Category
81–100	Very valid	Very good
61–80	Valid	Good
41–60	Moderately valid	Fair
21–40	Less valid	Poor
0–20	Invalid	Very poor

Source: Hartini dkk. (2018); Widoyoko (2016)

Table 3. N-Gain Categories

N-Gain Score (g)	Category
$g \geq 0,7$	High
$0,3 \leq g < 0,7$	Medium
$g < 0,3$	Low

Source: Meltzer (2002)

RESULTS AND DISCUSSION

Media Validity

Validation was conducted on the material, media, and test items by three validators (Table 4). Material validation by two validators yielded average scores of 89 (very valid) and 71 (valid). The highest score was given to the presentation quality aspect, while the lowest score came from the second validator in the attitude development aspect (60), which was subsequently revised so that the material

could better stimulate students' caring, empathetic, and responsible attitudes toward the preservation of local biodiversity. Media validation by the media expert yielded an average score of 88 (very valid), with the highest score in the video aspect (100) and the lowest in the impact on user attitude aspect (80). Test-item validation yielded average scores of 80 and 72 (valid)

Table 4. Results of Material, Media, and Test-Item Validation

Validation Object	Validator	Mean Score	Category
Material	Validator 1 (material and test expert)	89	Very valid
Material	Validator 2 (material and test expert)	71	Valid
Media	Media expert	88	Very valid
Test Items	Validator 1 (material and test expert)	80	Valid
Test Items	Validator 2 (material and test expert)	72	Valid

These results indicate that the material, media, and test items fall within the valid to very valid categories, with mean scores of 80 for the material, 88 for the media, and 76 for the test items, making them suitable for use in IPAS Project learning. The high quality scores are supported by the characteristics of

Virtual Reality, which combines visual, auditory, and kinesthetic elements and may help students focus on the concepts being studied (Liu et al., 2022). Virtual Reality also enables students to explore immersive three-dimensional environments, providing a more authentic learning experience compared to conventional media (Mukti &

Erdianti, 2025). Differences in learning gains between classes should nevertheless be interpreted cautiously. Immersive learning outcomes are shaped by affective and cognitive factors such as interest, motivation, self-efficacy, and self-regulation (Makransky & Petersen, 2021), and meta-analytic evidence shows that the effect of immersive Virtual Reality varies with educational level and field of study (Coban et al., 2022). Because motivation, engagement, and prior knowledge were not measured in this study, class differences (e.g., between X AKL and the other classes) may reflect student characteristics, such as prior knowledge or program-specific learning orientation, rather than the medium alone. Future studies should measure these variables directly.

These findings align with Febriana (2023), who reported the feasibility of Virtual Reality interactive learning media with expert ratings of 92.6% from material experts and 88.7% from media experts, as well as with Supriadi (2019), who demonstrated a very high level of validity for Virtual Reality based on evaluations by several experts. The valid categorization of the test items indicates that the questions

are capable of measuring the competencies being developed along with their indicators and materials, and valid instruments will guide students in acquiring knowledge and developing skills accurately (Ati MZ et al., 2021).

Media Practicality

Practicality was evaluated through learning implementation by teachers, student activities, and student responses (Tables 5 and 6). Across all trial groups, the learning implementation scores ranged from 90 to 98, and student activity scores ranged from 89 to 99, all falling into the very good (very practical) category.

Learning implementation scores increased from the first meeting to the third across all groups, indicating that teachers became more proficient in managing instruction using Virtual Reality media. Student responses were overwhelmingly positive: in the limited trial, 48% of students strongly agreed and 52% agreed, while in the broad trial, 54% strongly agreed and 46% agreed; no students expressed disagreement, strong disagreement, or neutrality leaning toward negative responses.

Table 5. Scores for Learning Implementation Observation and Student Activity (Meetings 1, 2, and 3)

Trial Group	Observed Aspect	Observer 1	Observer 2
Limited	Learning implementation	90; 92; 95	90; 92; 95
Limited	Student activity	92; 93; 89	94; 95; 95
Broad (X AKL)	Learning implementation	95; 97; 98	94; 95; 97
Broad (X AKL)	Student activity	93; 95; 96	96; 98; 96
Broad (X APHP and X ATPH)	Learning implementation	93; 94; 98	92; 94; 97
Broad (X APHP and X ATPH)	Student activity	92; 94; 95	95; 96; 99

Table 6. Percentage of Student Responses to Learning Using Virtual Reality Media

Student Response	Limited Trial (%)	Broad Trial (%)
Strongly agree	48	54
Agree	52	46
Less agree (Somewhat agree)	0	0

Disagree	0	0
Strongly disagree	0	0

The excellent implementation of learning across every syntax indicates that the teacher was able to execute the instructional steps according to the designed lesson plans (Wibawa dkk., 2017). The observed student activities included answering stimulus questions, working in groups, collecting data, and analyzing observation results. These achievements align with Fernanda et al. (2024), who reported an Android-based Virtual Reality learning media with a mean practicality of 90.7% (very practical), and with Hapiz's (2020) view that increased student activity is reflected in active questioning, answering questions, enthusiasm, and learning initiative. The overwhelmingly positive response from all students reinforces the findings of Chuang et al., (2023) that more than 82% of students responded positively to the integration of Virtual Reality in learning, and aligns with the perspective that Virtual Reality provides an interactive and

immersive learning experience, making abstract concepts easier to understand (Mukti & Erdianti, 2025).

Media Effectiveness: Critical Thinking Skills

The critical thinking test demonstrated improvements across all indicators in both the limited and broad trials (Table 7). In the limited trial, the largest increase occurred in the explanation indicator (18% to 77%; +59 percentage points) and the smallest in the evaluation indicator (23% to 53%; +30 points). In the broad trial, the largest increase occurred in the interpretation indicator (25% to 75%; +50 points) and the smallest in the analysis indicator (26% to 61%; +35 points). The N-Gain values for critical thinking fell into the medium category across all meetings and groups, ranging from 0.54 to 0.61, and increased progressively from the first meeting to the third (Table 8).

Table 7. Achievement of Each Critical Thinking Indicator (%)

Indicator	Limited Trial			Broad Trial		
	Pretest	Posttest	Difference	Pretest	Posttest	Difference
Interpretation*	33	77	+44	25	75	+50
Analysis	23	60	+37	26	61	+35
Evaluation	23	53	+30	29	65	+36
Inference	30	80	+50	25	73	+48
Explanation	18	77	+59	29	77	+48
Self-regulation	25	63	+38	21	61	

Table 8. Pretest, Posttest, and N-Gain Results of Critical Thinking Skills

Group	Meeting	Pretest	Posttest	N-Gain	Category
Limited trial	1	26	66	0.54	Medium
	2	27	68	0.56	Medium
	3	24	70	0.61	Medium
Broad trial: X AKL	1	30	68	0.54	Medium

Broad trial: X APHP and X ATPH	2	27	69	0.56	Medium
	3	25	70	0.61	Medium
	1	25	67	0.56	Medium
	2	25	68	0.57	Medium
	3	24	70	0.61	Medium

The improvement in the explanation and inference indicators is consistent with Agnafia (2019) and Khairunnisa et al. (2022), who found that students were well able to provide explanations and draw interesting conclusions following instruction. The relatively lower improvement in the analysis and evaluation indicators was influenced by class characteristics: tenth-grade students in classes X TM and X ATU during the limited trial tended to be less motivated, passive, and unstable in their focus, requiring teachers to repeat explanations. This condition limited the cognitive engagement necessary for analysis and reasoning, and the ability to construct scientific explanations is indeed still weak among most students (Asysyura et al. 2023).

Conversely, students in class X AKL, who were more active and responsive, were able to utilize the interactive stimuli of Virtual Reality optimally; high engagement in active learning is closely related to a sense of ownership, self-efficacy, and resilience (Graham et al., 2023). The progression across meetings indicates that students became increasingly accustomed to critical thinking, as critical thinking skills can be enhanced through practice and habituation (Oktariani, 2020). These results also

reinforce the findings of Langit et al. (2023), showing that Virtual Reality media assisted by MilleaLab software influences students' critical thinking skills in science learning. Another study by Sumiyaty et al. (2025) noted that transforming science learning through the assistance of Virtual Reality media enhances critical thinking skills regarding the solar system material.

Media Effectiveness: Concept Understanding

In the limited trial, all indicators of concept understanding were below 45% on the pretest; the highest indicator was explaining (40%), while classifying and summarizing were the lowest (15% each). After learning, all indicators improved, with classifying remaining the lowest indicator (42%), while exemplifying and explaining achieved the highest scores. In the broad trial, the highest indicator during the pretest was exemplifying (29%), and all indicators increased on the posttest, with the highest achievements in interpreting and explaining (86) and the lowest in classifying (54). The N-Gain for concept understanding fell into the medium category across all meetings (Table 9), ranging from 0.56 to 0.65 in the limited trial, 0.62 to 0.68 in class X AKL, and 0.47 to 0.51 in the combined classes X APHP and X ATPH.

Table 9. Pretest, Posttest, and N-Gain Results of Concept Understanding

Group	Meeting	Pretest	Posttest	N-Gain	Category
Limited trial	1	27	68	0.56	Medium
	2	27	70	0.59	Medium
	3	21	72	0.65	Medium
Broad trial: X AKL	1	19	71	0.64	Medium
	2	26	72	0.62	Medium
	3	26	76	0.68	Medium
Broad trial: X APHP and X ATPH	1	22	59	0.47	Medium
	2	20	61	0.51	Medium
	3	28	62	0.47	Medium

The significant increase in the exemplifying indicator aligns with Sani et al. (2024), who reported that this indicator achieved the highest N-Gain (0.68) because students were given the opportunity to apply concepts to real-life contexts, making the concepts more relevant and memorable. The classifying indicator still requires reinforcement through activities that provide students with more opportunities to identify characteristics, compare traits, determine criteria, and categorize the biodiversity of a given object. The increase in N-Gain from the first meeting to the third in the limited trial and in class X AKL is consistent with Azizah & Marisa., (2025), who reported that the experimental class average increased by 57.80% after Virtual Reality learning, as well as with the finding that Virtual Reality media helps students understand abstract and complex concepts (Mukti & Erdianti, 2025). One plausible explanation is that Virtual Reality can help manage extraneous cognitive processing when it is well designed. Learning in immersive environments can be demanding, because rich visual stimuli may increase extraneous load (Makransky & Petersen, 2021).

However, design features such as signaling can direct attention to relevant information and reduce extraneous load in Virtual Reality-based learning (Albus et al., 2021). The guided, structured presentation of ecosystem components in the developed media may therefore have supported students in concentrating on the target concepts. Because cognitive load was not measured in this study, this mechanism remains a theoretical interpretation rather than an empirical finding, and future research should include validated cognitive load instruments.

Research by Muiz et al. (2025) also demonstrates the positive effect of using Virtual Reality media in building science concept understanding. The lower achievement in the combined classes X APHP and X ATPH (0.47–0.51) compared to class X AKL (0.62–0.68) was likely influenced by classroom characteristics and student activity levels, as similarly observed in critical thinking skills.

CONCLUSION

The biodiversity literacy-based Virtual Reality media developed using the ADDIE model met the criteria for validity, practicality, and effectiveness within the

tested context. Expert validation rated the materials, media design, and assessment items as valid to highly valid. The media was also highly practical, with very practical learning implementation and student activities and positive responses from all students. It yielded medium-category improvements in concept understanding (N-Gain = 0.47–0.68) and critical thinking skills (N-Gain = 0.54–0.61) in tenth-grade IPAS Project learning. However, these findings cannot be generalized to the wider vocational high school (SMK) population. The trials were conducted in a single school using a purposive sample, so the results apply only to the subpopulation studied. SMK students differ across institutions in study program, prior knowledge, device availability, and internet access, which may influence immersive learning. The media's focus on the Nantu Wildlife

Reserve may also limit its impact in regions with different local contexts. Future testing across multiple schools and regions, with a control group, is therefore needed. Implementing Virtual Reality also requires teacher guidance, stable internet connectivity, and well-managed time. Because biodiversity literacy served as a design foundation rather than a measured outcome, the observed gains reflect improvements in concept understanding and critical thinking, not in biodiversity literacy itself. Future research should assess its knowledge, attitude, and action dimensions, compare this media with other instructional tools, and strengthen activities targeting the indicators with lower gains: classifying in concept understanding, and analysis and evaluation in critical thinking.

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