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CREATING DIGITAL TEACHING MATERIALS THAT UTILIZE AUGMENTED REALITY HAS THE POTENTIAL TO ENHANCE STUDENT'S CRITICAL THINKING ABILITIES

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Abstract

This study aims to create digital educational resources centered around Augmented Reality (AR) that focus on plants' various parts and functions, with the intention of enhancing critical thinking abilities. The study follows a development research approach, utilizing the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) research design. Data was gathered through expert evaluations, teacher assessments, test questions, student worksheets, and student response questionnaires. The data was then quantitatively analyzed descriptively. The findings revealed that the teaching materials received high ratings from experts, with a score of 96% and a CVR and CVI of 0.95. Before using the teaching materials, students' critical thinking skills were measured at 62.55, significantly improving to 87.55 after implementing the materials. The increase in students' critical thinking skills was measured at 65.55. Additionally, 91% of students strongly agreed with the effectiveness of the Augmented Reality (AR)-based digital teaching materials. This research encourages technology developers to create more AR-based educational content that suits the needs of the curriculum and the target skills they want to improve, such as critical thinking.

Keywords: Critical Thinking, Augmented Reality, Feasibility, Interactive, Teaching Materials

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INTRODUCTION

Creating digital teaching materials that utilize augmented reality (AR) is increasingly urgent due to the declining interest in traditional educational resources and the need to enhance students' critical thinking (CT) abilities. Research indicates that AR can significantly improve engagement and learning outcomes, making it a valuable tool in modern education. Studies show that AR-based instructional media, such as pocketbooks and games, lead to significant improvements in students' critical thinking scores, with average test scores rising from 51.5 to 76.6 (Pratiwi & Nugraheni, 2024) and substantial gains in mathematics learning (Pratiwi & Nugraheni, 2024). In addition, AR materials can captivate students' interest, moving away from traditional printed resources, as evidenced by findings that students prefer interactive formats over static ones (Saputri & Asrizal, 2023). AR effectively also helps students grasp complex topics, such as elements and compounds, by providing visual representations that enhance understanding (Zaroul et al., 2021).

Although augmented reality (AR) has the potential to improve students' critical thinking skills significantly, its effectiveness may vary depending on the student's prior knowledge and the quality of the AR content (Zaroul et al., 2021). Integrating augmented reality (AR) as a learning tool presents challenges, such as the significant time and financial investment required, which may be impractical for some educational institutions (Zuniari et al., 2022). Furthermore, educators may require additional training to effectively integrate AR into their teaching methods, and some students may require assistance to access the necessary technology (Dhaas, 2024). Therefore, while AR has the potential to transform educational practices and enhance critical thinking, careful consideration of resources, training, and equity is essential for successful implementation.

In the ever-evolving digital era, digital teaching materials have become integral to the educational process. Digital teaching materials, which involve various forms of material such as e-books, learning videos, interactive software, and online platforms, allow for easier access, higher interactivity, and better adaptation to student learning styles. Various recent studies underscore the significance of digital teaching material design. For instance, Clark (n.d.) emphasizes its importance, while Mayer (2014) contributes to the field by developing the Multimedia Learning Theory. Additionally, Hwang et al. (2012) evaluate the impact of digital games on learning. Teaching materials serve as learning resources that encompass content, methodologies, parameters, and assessment strategies, all carefully designed to facilitate educators' acquisition of desired competencies.

Augmented Reality (AR) in learning involves integrating AR technology to enrich the learning experience. It involves three main aspects: 1) Specific learning context; 2) Use of AR technology, such as AR hardware and software; and 3) Learning outcomes, including increased understanding and retention of material. Supporting journals include *"Augmented Reality in*

Education: A Meta-Analysis" (2018) by Akçayır and Akçayır and "The Effectiveness of Augmented Reality in Educational Settings" (2015) by Radu. These studies support AR's potential to improve learning outcomes and motivate students in various educational contexts.

Critical thinking competencies are important in this swiftly converting and complicated records era. Abrami et al. (2015) determined that teaching that explicitly goals essential thinking competencies can notably enhance students' abilities. The traits of college students who seriously display intellectual thinking capabilities include reasoning, analysis, problem fixing, studying comprehension, medical thinking, creative wondering, comparing, and making the right choices (Sarigoz, 2012). essential questioning is convergent wondering, good judgment, and reasoning (Seventika et al., 2018). Numerous researchers have tried to bolster the improvement of crucial questioning talents, which includes the constructivist-based software gaining knowledge of strategies (Adak, 2017) scaffolding approach. (Alake & Ogunseemi, 2013).

The integration of Augmented Reality (AR) in educational resources presents both opportunities and challenges. Previous studies have highlighted limitations in AR applications, such as conflicting findings exist regarding AR's impact on cognitive load, with some studies indicating increased demands that may hinder performance (Aldeeb et al., 2024). In addition, many studies, such as those using purposive sampling, limit the applicability of findings across diverse educational settings (Tan & Tay, 2021). Prior research often fails to sustain student motivation over time, particularly in subjects like plant education where practical observation is limited (Chang et al., 2016).

This research specifically targets plant education, utilizing AR to visualize complex biological processes, which has been underexplored (Chang et al., 2016). By employing a robust ADDIE framework, the study ensures thorough assessment and iterative improvement of educational resources, addressing previous methodological shortcomings (Cheng, 2023). Unlike prior studies, this research emphasizes the development of critical thinking skills through interactive AR experiences, setting it apart from traditional learning methods (Hung et al., 2017). While previous studies have laid the groundwork for AR in education, they often overlook the nuanced application of AR in specific subjects like botany. This study not only fills that gap but also aims to create a more engaging and effective learning environment. This study will address these gaps by developing AR resources focused on plant education and enhancing critical thinking through a structured ADDIE approach. These skills are necessary to face the 21st century and achieve sustainable development goals.

METHOD

This research and development (R&D) study aims to create interactive digital teaching material based on augmented reality to improve students' critical thinking skills. The design of this study adopted the ADDIE model (analyzing, designing, developing, implementing, and

evaluating) (Branch, 2009). ADDIE leads the development of effective and structured teaching materials and ensures quality through systematic processes. Analysis: Understanding learning needs and goals. Design: Designing learning structures, materials, and media. Develop: Producing teaching materials according to the design. Implementation: Applying teaching materials in the teaching process. Evaluate: Measuring effectiveness and making improvements. This study focuses on the feasibility of developing teaching materials based on the contributions and suggestions of teaching materials experts, learning media experts, and teachers and empirical testing on students.

The similarity test of two variances in determining population homogeneity was carried out at the beginning of the implementation. Because the population is homogeneous, the sample is selected using the *two-paired random sampling* technique. Fifth grade as a sample class. Product trials with 20 fifth-grade students as respondents. Final product trials are carried out with *Pretest-Posttest Group Design*. After selecting the research sample, 40 students were pretested. The pretest questions consist of 15 multiple-choice questions. The results of *this pretest* will be used to determine students' initial ability. The next stage of this sample class is learning using Augmented Reality (AR)-based digital teaching materials used by students at home or studying independently.

Trials are carried out to test the feasibility of developed teaching material products. The trial in this study includes two stages. The first trial was a media test conducted by two media experts and two material experts. Assessment by media experts covers aspects of audio-visual display and software engineering. Assessment by material experts includes aspects of basic competence, material content, and critical thinking skills.

This research involved two material expert validators and two media expert validators. In addition, 20 elementary school teachers will participate as users in providing assessment and feedback on the developed teaching materials. The effectiveness test of teaching materials was conducted on 40 students in one of the elementary schools in Cianjur Regency, Indonesia.

The results of increasing students' critical thinking skills become a measuring tool to determine effectiveness by conducting *pretests and posttests*. The increase in learning outcomes can be known by calculating the gain value (normalized gain or N-gain) (Hake, 2007). The eligibility test for educational material includes expert confirmation sheets, teacher reviews, and student admission. There are two authentication boards: the hardware expert authentication board and the communication expert authentication board. The validation aspect of the physical expert includes the evaluation of content, presentation, and language, while the communication aspect includes utility, functionality, and visual communication. The student documentation acceptance instrument was adopted from (*Sriadhi Gautama,+19.+JISD+Vol.+4.+No.4+Sigit+Setiawan+687-697,* n.d.) and includes four items, namely documentation, assessment, multimedia design and facilities, and teaching effectiveness.

Critical thinking skills are measured using critical thinking ability tests in the form of essays. There are ten questions with a reliability coefficient of 0.86. Another tool used is a board that observes the learning process when students use the educational material that has been developed.

Based on the study objectives, data collection begins with validation by material experts and media experts. In addition to providing quantitative assessments, validators also provide feedback and suggestions on educational materials made. In addition, teaching materials are provided to teach teachers the ratio of content validity (CVR) and content validity index (CVI). The teachers also gave their opinions and suggestions. After the education document is revised, the education document will be tested on the student to obtain student admission data. The final data collection stage included distributing validated interactive educational materials to eighth graders. After using the educational material, a test of critical thinking skills is performed.

The analysis of due diligence by experts is carried out using the following formula:

$$Percentage\ of\ feasibility = \frac{\Sigma scores\ obtained}{total\ scores} \text{ x } 100\ \% = \ldots\ldots\ldots\ldots$$

The calculation results are categorized according to the feasibility level, as shown in Table 1.

Table 1. Categorization of the feasibility level of teaching materials

Obtained value (%)	Golongan
80 – 100	Valid
60 – 79	Quite valid
40 – 59	Kurang valid
0 – 39	Invalid

Teacher assessment consequences are calculated using the content material validity ratio (CVR) and content material validity index (CVI). The calculation of CVR is accomplished using the subsequent system:

$$CVR = \frac{Ne - \frac{N}{2}}{\frac{N}{2}} = \ldots\ldots\ldots\ldots$$

Ne is the range of respondents who expressed "yes" or agreed, and N is the full range of respondents. The CVR cost received changed into then in comparison with the CVR table value (Lawshe, 1975) at p = zero.05 for a one-sided check (table 2). A rial-instructor pair is appropriate if the calculated CVR fee exceeds the table.

Table 2. Minimum value of CVR in one-sided test at p = 0.05

Number of respondents	Nilai CVR minimum	Number of respondents	Nilai CVR minimum
5	0.99	13	0.54
6	0.99	14	0.51
7	0.99	15	0.49
8	0.85	20	0.42
9	0.78	25	0.37
10	0.62	30	0.33
11	0.59	35	0.31
12	0.56	40	0.29

The CVI value is determined by calculating the average gain of the CVR value (Lawshe, 1975) using the following formula:

$$CVI = \frac{\Sigma CVR}{number\ of\ sub{-}statements\ received} = \ldots\ldots\ldots\ldots$$

Student admission outcomes are calculated using formula one and categorized in Table 3.

Table 3. Categorization of student admissions to digital teaching materials

Acceptance percentage (%)	Golongan
81-100	Very good
61-80	Good
41-60	Adil
21-40	Miskin
0-20	Very Poor

The subsequent step is to provide revised interactive coaching materials to forty-fourth-grade elementary school students to gauge their crucial wondering talents and scientific attitudes. Students' vital wondering capability ratings are analyzed descriptively and quantitatively. Primarily based on the outcomes of its implementation, an assessment was completed to determine the effectiveness of coaching substances evolved to be used by elementary education college students in reading plant parts and their features.

RESULTS AND DISCUSSION

The product produced in this study is a digital teaching material based on *Augmented Reality* (AR) designed using *EyeJack Creator 2022 software*. The material used is plant parts and their functions in fifth-grade students of elementary school. The research data includes the characteristics of teaching materials. Teaching substances is part of gaining knowledge of assets that instructors and college students can utilize to guide mastering success according to the

times. presently, the need for digital and interactive coaching materials is very high (Critical Thinking Skills and Sustainability Awareness for the Implementation of Education for Sustainable Development Ekamilasari *, Anna Permanasari, Indarini Dwi Pursitasari, n.d.) The trade from printed coaching materials to interactive electronic teaching substances can lessen student boredom in learning and provide new studies in the studying method; these coaching materials can be advanced with multimedia programs because they can integrate numerous media in the form of textual content, photographs, images, music, animation, video, and interaction in virtual files (Liu et al., 2018). Virtual coaching substances may be used broadly with the aid of students and are not confined by space and time. Based on this, virtual teaching materials based on Augmented truth have been advanced on plant parts and their capabilities.

The teaching materials developed were then examined for feasibility using two cloth specialists and two media experts. The decision is based primarily on content material, presentation, and language additives. The validation test results are shown in Table 4.

Table 4. Effects of the feasibility evaluation of teaching substances

Assessment Aspect	Validator 1 (%)	Validator 2 (%)	Average (%)
Content	87.5	95.0	90.0
Aspects	87.0	95.0	90.0
Language	95.0	90.5	92.2

Based on Table 4, the overall average content feasibility assessment of expert assessments is 90.73%. The results of the expert assessment show that the lowest score is for the feasibility of the presentation. This is in line with the advice of experts, as shown in Table 5, which is mostly related to the presentation aspect.

Table 5. Suggestions and revisions made by validators

No	Expert Advice	Revision
1	3D Object Caption is not displayed in its entirety	Captions on objects are hidden and can be called if needed
2	Command/action buttons displayed more clearly	Command button improvements are more precise and clearer
3	Animations on objects do not need to be too crowded	Re-adjustment of object animation appearance

Media experts assess ease *of* use, *functionality*, and visual communication. The assessment results are shown in Table 6.

Table 6. The results of the feasibility assessment of teaching materials by experts

Assessment Aspect	Validator 1 (%)	Validator 2 (%)	Average (%)
Uses	97.5	95.0	96.25
Functionality	100	100	100.0
Visual Communication	95.0	90.5	92.75

Based on Table 6, the average normal score is ninety-six. 33% included in the legitimate class. The best score is for capability. These consequences show that the feature of coaching substances is functioning properly and is easy to understand; the chosen function can show the section caption properly; color composition is appropriate; thrilling visualizations; teaching substances are without problems reachable; and the content material is simple to apprehend. (Davids et al., 2015) Findings display the significance of usefulness in developing coaching materials because it can determine user pleasure with coaching materials that use computer systems (Alshehri et al., 2019)—measured the usability of web-based interactive multimedia, with the consequences of the usability price of teaching substances getting a mean value of 96.25%. Twenty instructors then assessed the revised teaching substances to determine CVR and CVI ratings; the consequences are shown in Table 7. The aspects of content material evaluation assessed are content feasibility, presentation, and language.

Table 7. Results of the feasibility assessment of teaching materials by teachers

No	Assessment Aspect	∑ ∑	CVI
1	Content	6.5	0.97
2	Performance	6.0	0.95
3	Language	6.5	0.92
		Average CVI score	0.95

Table 7 indicates that the best center CVR is the content material factor of 6.5. This suggests that teaching substances are according to core abilities, fundamental capabilities, learning goals, pupil improvement stages, the relevance of the cloth provided to competency signs, correctness in handing over the material, suitability to scholar wishes, and suitability of pupil worksheets and quizzes/evaluations to increase students' critical wondering talents. CVI is 0. 0. ninety-five, belonging to the high class. The excessive feasibility issue shows that the coaching substances evolved can continue to the pupil reaction degree, which wishes to be decided that allows you to be tested on students. Aspects measured consist of scholar recognition of the fabric, evaluation, media layout, centers, and pedagogical effects Sriadhi Gautama,+19.+JISD+Vol.+4.+No.4+Sigit+Setiawan+687-697 (n.d.). The effects of student responses to the mastering material of plant parts and their capabilities are proven in discern 1.

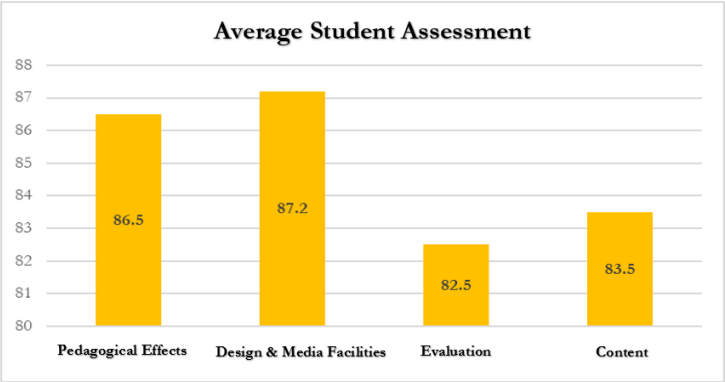

Figure 1. Student Response Results

Based on the statistics in parent 1, the results of college students' responses to the four aspects are very comparable, with a mean rating of 84—90 percent. The most widespread score received associated with the effect of design centers media changed to 87.2. This suggests that the evolved teaching materials have met college students' needs related to changes in getting to know patterns and can foster hobbies and extra lively studying, enhancing vital questioning competencies. Several research studies were conducted to determine the elements that impact customers in getting hold of m-gaining knowledge and impartial studying (Liu et al., 2018), and students can appear extra stimulated and improve their overall performance by using interactive coaching substances. This is in keeping with Kong's opinion (2018), which states that getting to know can increase involvement between parents and children and increase knowledge of motivation and scholarly performance. Moreover, digital teaching materials can be provided to college students, and their critical questioning skills may be determined after using those coaching substances.

Teaching materials tested for feasibility by experts, assessed or tested by teachers, and accepted by students are then given to students. The role of the teacher is to provide initial direction and accompany students in learning digital teaching materials based *on Augmented Reality* (AR) on plant parts and their functions.

The effectiveness of using digital teaching materials to improve students' critical thinking skills refers to analyzing students' written test results, including both *pretest* and *post-test scores*. To determine the effectiveness of learning using digital teaching materials to improve students' thinking skills, N-Gain is adapted from the Hake equation (1999). This discussion will describe the effectiveness of learning using Augmented Reality (AR)-based digital teaching materials on students' overall critical thinking skills. The following will be presented as the study results in Figure 2.

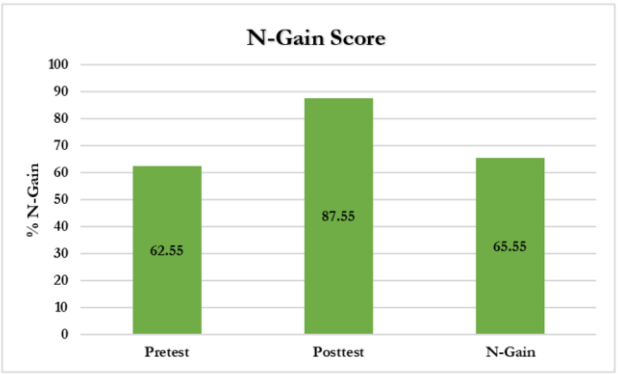

Figure 2. Improved overall critical thinking skills

The data in Figure 2 shows students' average pretest and posttest scores. Based on the results of N-Gain, there is an increase in the overall results of the Shiva critical thinking ability test in the moderate category. Research and development of digital teaching materials are supported by the results of development research by Ibrahim (2017); mobile learning products are interactive so that they can attract the attention of students actively; this is in line with research conducted by Nopita (2016) learning carried out with *mobile learning* helps in the carrying capacity of mastery of concepts.

The research results on developing digital teaching materials based *on Augmented Reality* (AR) to improve critical thinking skills in fifth-grade students found increased science literacy in the domain of content, competence, and science attitudes of students.

Learning outcomes or achievement of critical thinking skills in students can be seen in Table 8. Table 8 suggests that scholars' common vital wondering skills are inside the accurate class, with a mean rating of 73. The reason is that the evolved teaching substances facilitate college students a good way to think severely. The material starts with presenting troubles in discourse, tables, figures, and films, which can require students to increase their crucial strengths.

Table 8. Results of students' critical thinking skills

Description	Score
Average	73
Score Minimum	51
Score Maximum	90
Standard Deviation	12
Range	42

The pupil learning technique is proven by using student activities to answer questions in coaching materials. Those questions are packaged and provided in diverse paperwork, with

one accurate answer, and outlined by considering the essential questioning aspect. Therefore, Augmented reality (AR)-primarily based on virtual coaching materials- can enhance students' essential questioning talents. Similar research results were performed by improving critical thinking competencies (Usmaedi et al., 2020) by improving digital modules. Watson and Glaser (2008) nation that the components of critical thinking encompass (1) concluding, (2) assumptions, (three) deduction, (4) deciphering information, and (5) analyzing arguments. Those additives of essential questioning are used to measure someone's critical thinking capacity.

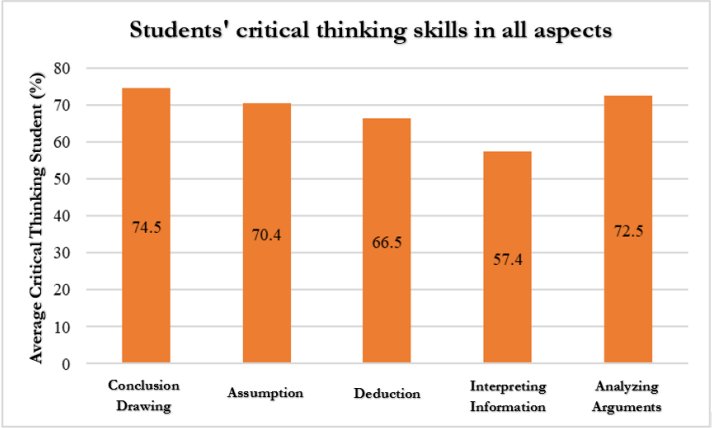

Figure 3. Students' critical thinking skills in all aspects

The best students' vital thinking skills are related to the interpretation thing, and the lowest is associated with the explanatory element (determine three). Step one college students take is to interpret the problem to get the perfect and appropriate answer. even as the best rating is the extent of interpretation due to the fact students are accustomed to defining a problem in coaching substances. This finding aligns with the effects of studies by Suwatra et al. (2018), which suggest that indicators defining statements/problems have the biggest percentage (74.5%) compared to different indicators. However, the location of this study is that college students' capability to explain the conclusions acquired continues to be low. College students study teaching substances independently, so different students or instructors do not mention the reasons defined. As a result, college students are much less in step with (Setyawan et al., 2019) the characteristics of someone who can suppose seriously, namely being able to resolve trouble with a positive goal, having the ability to investigate and generalize thoughts primarily based on present information, and being able to draw conclusions and clear up issues systematically with accurate arguments. Suppose a person can best remedy issues without understanding the cause to which the concept is applied. In that case, he can not be stated to be capable of thinking significantly.

The findings suggest that AR can transform traditional learning environments into interactive experiences, thereby enhancing cognitive engagement. For instance, Hanggara et al. demonstrated that AR-based mathematics games significantly improved critical thinking skills among students compared to conventional methods (Hanggara et al., 2024). Dhaas also highlighted AR's potential to create meaningful learning experiences across various subjects (Dhaas, 2024). This study also shows that AR can improve critical thinking by providing immersive learning experiences that encourage active participation and problem-solving (Alkhabra et al., 2023).

The results resonate with theories advocating for experiential learning, where active participation leads to deeper understanding. Al-Said et al. found that immersive virtual reality training improved critical thinking by reducing cognitive load, further supporting the notion that innovative teaching methods can enhance cognitive skills (Al-Said et al., 2024). Similar findings were reported by Aldeeb et al., who noted that AR enhances self-efficacy and motivation, which are crucial for developing critical thinking skills (Aldeeb et al., 2024). Ou Yang et al. demonstrated that AR-based tools improve computational thinking, a component closely related to critical thinking (Ou Yang et al., 2023).

Despite these promising results, limitations such as varying cognitive loads and the need for effective implementation strategies were noted (Aldeeb et al., 2024). Future research should focus on optimizing AR applications in diverse educational contexts and exploring long-term impacts on critical thinking development. In summary, while the study contributes significantly to the understanding of AR in education, it also highlights the necessity for ongoing research to address its limitations and maximize its educational potential.

CONCLUSION

Based on the results of development studies that have been carried out on Augmented *Reality (AR)-based digital teaching materials* on plant parts and their functions. It can be declared feasible and valid by acquiring CVR and CVI values of 0.95, which means this digital teaching material is suitable for science teaching materials. The increase in students' critical thinking skills can be seen in the *pretest and* posttest results before using digital *teaching materials; student pretest* results amounted to 62.55, while after students used teaching materials, student *posttest* results amounted to 87.55. The increase in critical thinking skills measured from the *pretest* and *post-test scores* obtained by N-Gain scale students got a score of 65.55, meaning this study's achievement falls into the "medium" category.

Digital teaching materials based on *Augmented Reality* (AR) have critical thinking content that is based on N-Gain calculations, namely in the competency domain with five indicators: 1) concluding 74.5%, 2) assumptions 70.4%, 3) deductions 66.5%, 4) interpreting information 57.4% and, 5) analyzing arguments 72.5%.

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