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DEVELOPMENT AND PRACTICALITY OF CTML-BASED 3D DIGITAL LEARNING MEDIA FOR CELL STRUCTURE

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ABSTRACT

This study developed three-dimensional (3D) digital learning media for cell structure using the Cognitive Theory of Multimedia Learning (CTML) and evaluated its expert-assessed feasibility and student-perceived practicality. Research and development followed the analysis, design, and development phases of the ADDIE model. Four experts assessed media feasibility, while 50 vocational-school students provided responses to general usability indicators and eight CTML-related design principles. Expert ratings were 95%, 95%, 95%, and 96%, yielding an arithmetic mean of 95.25%. General practicality reached 88.6%, whereas students' ratings of CTML-related design features averaged 88.88%. Coherence, pre-training, and modality jointly obtained the highest CTML-related ratings, at 90% each. These findings indicate that the developed media received highly favorable expert assessments and positive student responses regarding its practicality. The application of CTML principles provides a theoretical basis for organizing visual and verbal information in presenting cell structures, which are often difficult to understand through conventional representations. However, these results support only the preliminary feasibility and perceived practicality of the product and do not establish improved learning outcomes, enhanced conceptual understanding, or reduced cognitive load. Therefore, subsequent research should involve classroom implementation and controlled evaluation to investigate the media's effectiveness in supporting students' understanding of cell structure.

Keywords: 3D learning media; cell structure; CTML, multimedia.

INTRODUCTION

Education plays an important role in developing human resources capable of adapting to scientific and technological advances (UNESCO, 2021; OECD, 2023; Chugh et al., 2022; Mayer, 2021; Robiah et al., 2024). Through education, learners acquire the knowledge and skills needed to face future challenges and respond to changing societal demands (OECD, 2023; Mayer & Fiorella, 2021).

In the 21st century, learning emphasizes critical thinking, creativity, communication, and collaboration (OECD, 2023; UNESCO, 2021; Chugh et al., 2022). These competencies require appropriate strategies and digital media that support knowledge construction and technology integration (Smaldino et al., 2019; Putri et al., 2025; Hermansyah & Wulandari, 2025; Auliani et al., 2025).

Digital technology enables flexible learning and presents complex concepts through text, images, animation, audio, and video (Mayer, 2021; Smaldino et al., 2019; Radianti et al., 2020). Studies in Eduproxima have explored digital technology and learning media, including e-magazines, e-booklets, and virtual reality, to support science learning (Hermansyah & Wulandari, 2025; Hafidah et al., 2025; Zulfa et al., 2025; Muiz et al., 2025).

In biology learning, abstract and unobservable concepts require visualization to support concrete understanding (Campbell et al., 2020; Alberts et al., 2022; Reece et al., 2021; Mayer, 2021; Laubscher et al., 2024;

Reinke et al., 2021). Cell structure is a fundamental concept involving cell components, the spatial relationships among organelles, and the relationship between organelle structure and function (Alberts et al., 2022; Campbell et al., 2020; Reece et al., 2021; Merchant et al., 2021; Laubscher et al., 2024). Understanding these concepts may be challenging because students need to connect organelle positions with their functions and understand cellular processes that cannot be directly observed. When learning relies on separate two-dimensional illustrations, these relationships may be difficult to comprehend as an integrated system. Therefore, appropriate media is needed to visualize cell structures and their relationships more clearly (Reece et al., 2021; Smaldino et al., 2019; Mayer, 2021; Merchant et al., 2021).

Initial observations and interviews with Biology teachers at one vocational school in Pekanbaru showed that cell structure learning relies on textbooks and slides. Approximately 70% of students struggled with abstract, microscopic concepts, while 70% found two-dimensional images insufficient to represent organelle shapes and relationships. Consequently, students tended to memorize rather than understand conceptual relationships.

Understanding cell structure requires knowledge of organelle spatial relationships, structure-function relationships, and unobservable cellular processes (Alberts et al., 2022; Campbell et al., 2020; Reece et al., 2021). These concepts are difficult to understand through separate two-dimensional illustrations, highlighting the need for media that clearly presents cell structures and their relationships.

Three-dimensional (3D) digital media offers an alternative for visualizing abstract concepts. Previous studies in *Eduproxima* have discussed digital technologies, media development, and approaches to supporting conceptual understanding (Hermansyah & Wulandari, 2025; Auliani et al., 2025; Zulfa et al., 2025; Hafidah et al., 2025; Muiz et al., 2025). However, visualization alone does not ensure meaningful learning; media design must consider how learners select, organize, and integrate information with prior knowledge.

The Cognitive Theory of Multimedia Learning (CTML) explains that learning involves limited-capacity visual and verbal channels and active information processing (Mayer, 2021; Mayer & Fiorella, 2021). Applying CTML principles to 3D digital media may help organize information to support understanding of cell structure and function. However, their integration into 3D media specifically designed for cell structure requires further investigation.

Therefore, this study aimed to develop CTML-based 3D digital learning media on cell structure and determine its validity and practicality.

METHOD

This study employed a Research and Development (R&D) method using the ADDIE model, limited to the Development stage. The Implementation and Evaluation stages at a broader learning scale were not conducted. Therefore, the findings are limited to the validity and practicality of the developed media.

The research subjects consisted of material, media, and learning experts, as well as students. The population comprised 50 students from two classes who had studied cell structure at one vocational school in Riau. Saturated sampling was

applied by involving all 50 students in the practicality test.

The development process comprised three stages: analysis, design, and development. The analysis stage identified learning needs, the design stage involved planning the video content, 3D visualizations, and research instruments based on CTML principles, and the development stage involved producing, validating, and revising the media based on expert feedback. A limited practicality test was subsequently conducted with students. Data were collected through observation, interviews, questionnaires, and documentation. Observation and interviews were conducted during the needs analysis, while questionnaires were used to obtain expert assessments and student responses.

During the practicality test, 50 students watched the 3D digital learning media video on cell structure, observed organelle structures and functions, and received teacher guidance. They then completed a practicality questionnaire covering media display and CTML principles. Documentation complemented the data.

Data were analyzed descriptively and quantitatively. Expert scores determined validity, while student responses determined practicality. Categories were very practical (81–100%), practical (61–80%), fairly practical (41–60%), less practical (21–40%), and impractical (0–20%). The media was considered practical if it achieved at least the practical category.

RESULTS AND DISCUSSION

3D digital learning media is developed by integrating eight CTML principles, namely contiguity, coherence, signaling, segmenting, pre-training, modality, multimedia, *and* personalization. The integration of these principles is reflected in the presentation of materials, visualizations, and media displays as shown in the following figure.

Figure 1. Design of 3D digital learning media on cell structure material based on cognitive processing theory.

Figure 1 shows the integration of contiguity, coherence, signaling, and segmenting in the 3D digital learning media. Contiguity is implemented through

the placement of text close to the corresponding visuals, helping students relate organelle names to their visual representations. Coherence is applied by excluding information that is not relevant to the learning objectives, while signaling emphasizes important information about cell structures. Segmenting is implemented by presenting the material in stages, allowing students to follow the explanations step by step (Mayer, 2021; Mayer & Fiorella, 2021; Çeken & Taşkın, 2022; Mayer, 2024). These design features are consistent with CTML, which emphasizes selecting and organizing relevant information during multimedia learning (Mayer, 2021; Fiorella & Mayer, 2018; Smaldino et al., 2019; Putri & Muhtadi, 2018). The combination of visual elements, text, and animation also provides different forms of representation to support the presentation of abstract cell structures (Chugh et al., 2022; Putri et al., 2024; Dewi & Saifuddin, 2022). However, these explanations describe the theoretical functions of the design features and do not demonstrate that students' information-processing efficiency improved.

The principles of pre-training, modality, multimedia, and personalization are reflected in the presentation of cell components and their functions. Pre-training is implemented by introducing key organelles before discussing their functions, helping students become familiar with the terminology used in the lesson. Modality is applied through narration accompanying the visual presentation, allowing students to receive verbal explanations alongside visual information. The multimedia principle is reflected in the combination of words and relevant visuals, while personalization is implemented through communicative language that presents explanations in a more conversational manner (Mayer, 2021; Mayer & Fiorella, 2021; Çeken & Taşkın, 2022; Fiorella & Mayer, 2018). These features are relevant to cell structure learning because the material involves microscopic components and complex relationships that are difficult to observe directly (Alberts et al., 2022; Campbell et al., 2020; Reece et al., 2021). The use of visual representations and verbal explanations may help students connect organelle structures with their functions (Dewi & Saifuddin, 2022; Hafzah et al., 2020; Mahariyanti et al., 2024). Nevertheless, the potential benefits of these features should not be interpreted as evidence that students' cognitive load decreased or their information processing became more efficient, as these outcomes were not directly measured in this study.

Overall, the eight CTML principles provide a theoretical basis for designing the 3D digital learning media by organizing relevant information, presenting organelles before their functions, and combining narration with visual representations. The findings of this study reflect the perceived validity and practicality of the media rather than direct changes in students' cognitive processes. Therefore, the application of CTML principles and students' responses to the media cannot, by themselves, establish improved information-processing efficiency or increased conceptual understanding of cell structure.

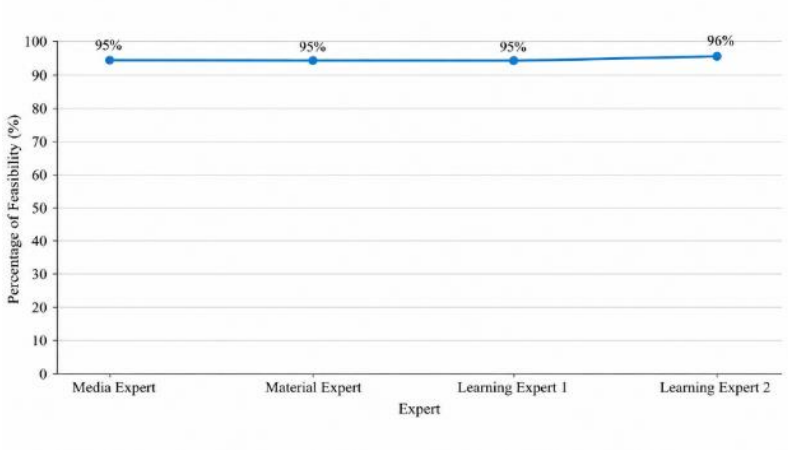
Furthermore, the media feasibility assessment was carried out by four experts consisting of media experts, material experts, learning experts 1, and learning experts 2 to determine the level of feasibility of the developed media. The results of the assessment are presented in Table 1.

Table 1. Results of Media Feasibility Assessment by Experts

Members	Eligibility Percentage (%)
Media Member	95
Material Expert	95
Learning Expert 1	95
Learning Expert 2	96
Average	**95,25**

To show the percentage of eligibility of each expert more clearly, the data in Table 1 is presented in the form of a line graph in Figure 2.

Figur 2. Media Eligibilty Results Based on Member Ratings



Furthermore, the feasibility assessment showed very high ratings from all experts. Media experts assessed appearance, technical, and presentation aspects; material experts assessed accuracy, suitability, and completeness; and learning experts assessed learning principles and information presentation. Learning Expert 2 gave the highest rating, while the others showed similar results, indicating consistent feasibility across all aspects.

These ratings indicate that the media integrates visualization, material accuracy, and learning presentation. This aligns with Mayer (2021) and Mayer and Fiorella (2021), who emphasize organizing information according to cognitive processing. Three-dimensional visualization and digital technologies can clarify complex concepts (Merchant et al., 2021; Radianti et al., 2020), while multimedia presents complex structures through various representations (Rolfe & Gray, 2011; Abdulrahaman & Faruk, 2020). Digital technology also supports interaction and flexible representation (Chugh et al., 2022; Rakhmawati et al., 2025; Sakr & Abdullah, 2024), as supported by García-Robles et al. (2024) and Salimi et al. (2024).

Previous studies support 3D visualization for abstract and complex materials (Radianti et al., 2020; Merchant et al., 2021; Hamilton et al., 2021; Laubscher et al., 2024; Reinke et al., 2021; García-Robles et al., 2024). Rolfe and Gray (2011) reported that multimedia supports learning outcomes in life science education (Abdulrahaman & Faruk, 2020), while Reinke et al. (2021) found that immersive 3D experiences support cell biology learning. The use of virtual reality in biology learning is also increasing (Rakhmawati et al., 2025), supported by

Maryanti et al. (2024) and Murtini & Cintamulya (2026). Mobile technology can visualize abstract biological concepts and increase engagement (Dewi & Saifuddin, 2022; Mahariyanti et al., 2024). Thus, 3D visualization is appropriate for microscopic cell structure materials (Alberts et al., 2022; Campbell et al., 2020; Reece et al., 2021; García-Robles et al., 2024).

Feasibility is also related to organizing information according to cognitive processes (Mayer, 2021; Mayer & Fiorella, 2021; Putri et al., 2025; Çeken & Taşkın, 2022; Cromley & Chen, 2025). Organized visual and verbal information helps students select, organize, and integrate information, while multimedia principles support structured presentation (Mayer, 2021; Mayer & Fiorella, 2021; Putri & Muhtadi, 2018; Anggraini & Zulyusri, 2023; Fitriani, 2025). Visual and multimedia representations support complex concept learning (Rolfe & Gray, 2011; Abdulrahaman & Faruk, 2020), while technology-based biology learning supports understanding, engagement, and learning experiences when appropriately designed (Rakhmawati et al., 2025; Nasution et al., 2022; Mahariyanti et al., 2024). Therefore, the average expert validation score of 95.25% indicates that the media meets the visualization, material, and learning criteria and is highly feasible for cell structure learning.

Furthermore, a practicality test assessed the acceptability and ease of use of the 3D digital learning media based on student responses. Data were collected through a questionnaire covering appearance, language, material, interactivity, and media benefits.

Table 2. Results of Media Proficiency Test by Students

Indicator	**Statement %**				
	1	**2**	**3**	**4**	**Average %**
Display	90	92	90	88	90
Language	87	88	87	89	88
Material	89	90	88	93	90
Interactivity	87	87	90	85	87
Benefits	88	88	89	88	88
	Average				**88,6**

Hfg To clarify the results of the media practicality test based on student responses, the results of the assessment are presented in the form of a graph in Figure 3.

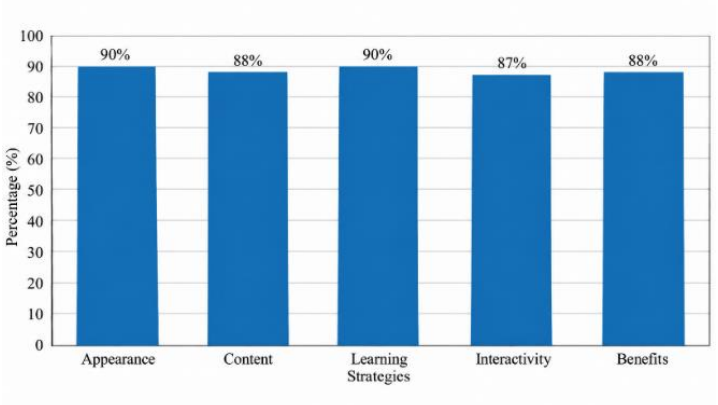


Figure 3. Results of Media Proficiency Test by Students

Based on the practicality test, the average scores were 90% for display, 88% for language, 90% for material, 87% for interactivity, and 88% for benefits, with an overall average of 88.6%. Thus, the 3D digital learning media was categorized as very practical.

The display aspect (90%) showed that the media was attractive, readable, well organized, and supported understanding through images, animations, and 3D objects. The language aspect (88%) indicated that the language, sentences, and biological terms were clear and easy to understand. The material aspect (90%) showed that the content was sequential, understandable, relevant to school learning, and introduced cells and organelles before their functions.

The interactivity aspect (87%) indicated that the media was easy to follow, supported gradual learning, and facilitated independent learning. The benefit aspect (88%) showed that the media supported understanding, learning interest, memory of organelle functions, and more effective and enjoyable learning.

Display and material obtained the highest scores (90%), indicating that the visual and content presentation met students' needs. Although interactivity was the lowest (87%), it still showed a positive response. Overall, the 88.6% score indicates that the media is very practical for cell structure learning.

These results are consistent with studies showing that visual technology-based media can support engaging learning experiences (Radianti et al., 2020; Hamilton et al., 2021; Merchant et al., 2021; Laubscher et al., 2024; Putri et al., 2024). Virtual environments and virtual reality can support engagement, understanding, and interaction with learning materials (Radianti et al., 2020; Merchant et al., 2021; Laubscher et al., 2024; Reinke et al., 2021).

Positive responses to language, material, interactivity, and benefits indicate that the media considers learner characteristics and information processing (Mayer, 2021; Mayer & Fiorella, 2021; Putri et al., 2025; Çeken & Taşkın, 2022). Targeted combinations of text, visuals, and narration support information processing, while effective learning media require clear appearance, understandable language, appropriate content, and ease of use (Mayer, 2021; Mayer & Fiorella, 2021; Smaldino et al., 2019). Therefore, the 88.6% score indicates that the media is visually appealing, understandable, interactive, and beneficial for cell structure learning (Mayer, 2021; Mayer & Fiorella, 2021; Smaldino et al., 2019; Putri et al., 2024).

Furthermore, an analysis was conducted to determine the application of Cognitive Processing Theory principles in the 3D digital learning media and their support for students' information processing. The results are presented in the following section.

Table 3. Results of Media Practicality Test Based on the Principles of Cognitive Processing Theory

No.	Cognitive Processes	Principle	Percentage (%)
1	Extraneous Processing	Contiguity	88
		Coherence	90
		Signaling	89

2	Essential Processing	Segmentation	88
		Pre-training	90
		Modality	90
3	Generative Processing	Multimedia	88
		Personalization	88
Average			**88,88**

Based on Table 3, the practicality test showed percentages ranging from 88% to 90%. Coherence, pre-training, and modality obtained the highest scores at 90% each, followed by signaling at 89%, while contiguity, segmenting, multimedia, and personalization each obtained 88%. The overall practicality reached 88.88%, indicating a very good student response to the application of CTML principles in 3D digital learning media.

The coherence principle obtained 90%, reflected in clear, relevant, and non-confusing information. This supports learners' focus by reducing unnecessary information (Mayer, 2021; Mayer & Fiorella, 2021; Çeken & Taşkın, 2022). Such targeted presentation is important for cell structure materials containing numerous terms and organelles (Alberts et al., 2022; Campbell et al., 2020; Reece et al., 2021; Fiorella & Mayer, 2018).

The pre-training principle also obtained 90% through the introduction of cells, organelles, and relevant biological terms before discussing their functions. This initial knowledge helps learners understand more complex material and connect organelles with their functions (Mayer, 2021; Mayer & Fiorella, 2021; Çeken & Taşkın, 2022; Alberts et al., 2022; Campbell et al., 2020; Reece et al., 2021).

The modality principle obtained 90% through narration combined with images and animations. This combination supports the presentation of abstract cell structures by providing visual and verbal information simultaneously (Mayer, 2021; Mayer & Fiorella, 2021; Fiorella & Mayer, 2018; Çeken & Taşkın, 2022; Reinke et al., 2021; Laubscher et al., 2024). These findings are consistent with studies showing that three-dimensional visualization can support understanding of abstract cell structures (Merchant et al., 2021; Radianti et al., 2020).

The signaling principle obtained 89% by emphasizing important information, particularly organelle names and functions, helping learners focus on key content (Mayer, 2021; Mayer & Fiorella, 2021; Çeken & Taşkın, 2022; Alberts et al., 2022; Campbell et al., 2020; Reece et al., 2021). Meanwhile, contiguity obtained 88%, indicating that the organized placement of text, images, and animations helped learners connect verbal and visual information (Mayer, 2021; Mayer & Fiorella, 2021; Fiorella & Mayer, 2018).

The segmenting principle obtained 88% because the material was presented sequentially from simple to complex concepts, making the learning process easier to follow (Mayer, 2021; Mayer & Fiorella, 2021; Çeken & Taşkın, 2022; Fiorella & Mayer, 2018). The multimedia principle also obtained 88% through the use of images, animations, and 3D objects, supporting clearer and more engaging presentation of cell structure materials (Mayer, 2021; Mayer & Fiorella, 2021; Putri et al., 2024; Smaldino et al., 2019).

The personalization principle obtained 88%, reflected in the use of communicative and easy-to-understand language that increased students' interest in

learning (Mayer, 2021; Mayer & Fiorella, 2021; Çeken & Taşkın, 2022; Putri et al., 2024). Overall, the 88.88% practicality result indicates that the eight CTML principles were well received and supported the structured presentation of cell structure materials (Mayer, 2021; Mayer & Fiorella, 2021; Çeken & Taşkın, 2022; Putri & Muhtadi, 2018; Merchant et al., 2021; Radianti et al., 2020; Reinke et al., 2021; Laubscher et al., 2024).

Based on the practicality test, coherence, pre-training, and modality obtained the highest percentage at 90% each. These principles represent clarity of information, provision of initial knowledge, and the combination of narration with visual elements, respectively. The following section presents documentation of their implementation in the 3D digital learning media

Figure 4. Application of the principles of *coherence, pre-training,* and *modality* in 3-dimensional digital learning media.

The image shows how CTML principles are applied in the developed media. The coherence principle is reflected in the presentation of targeted information and relevant elements. Pre-training is applied by introducing cell components and organelles before discussing their functions, while modality is applied through narration supporting images and animations. Thus, students not only see three-dimensional objects but also receive information that helps them understand the material.

The visualization of these three principles also supports the quantitative results. The 90% percentage for coherence, pre-training, and modality indicates that their application was well received by students. The media display and student assessments therefore show consistent support for the practicality of the 3D digital learning media.

In addition to quantitative results, student responses provided supporting information about their experiences using the 3D digital learning media. These responses described the ease of understanding the material, interest in the media display, and benefits of three-dimensional visualization.

Student responses were obtained after using the 3D digital learning media. The responses indicated that the media had an attractive appearance, was easy to use, and helped students understand cell structure material. Documentation of student responses is presented in Figure 5.

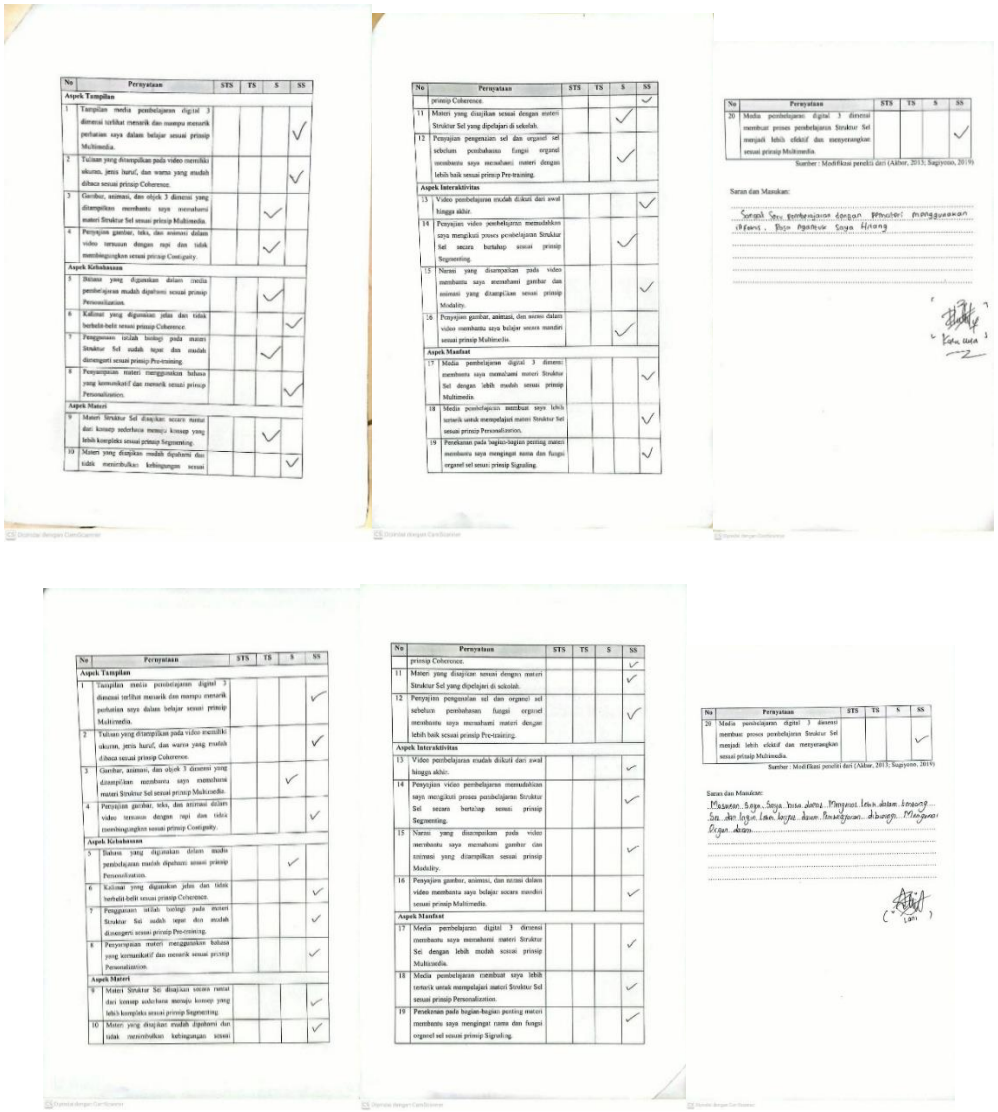


Figure 5. Students' responses to the use of 3-dimensional digital learning media

Based on the responses, students showed a positive response to the use of 3D digital learning media. The use of images, animations, three-dimensional objects, and narration made learning more interesting and helped students understand cell structure. This indicates that the media provides not only textual information but also visual representations that support understanding.

The responses also supported the assessment results for coherence, pre-training, and modality, which each obtained 90%. Clear information helped students follow the material, the introduction of cells and organelles provided a foundation for learning their functions, and narration supported understanding of images and animations. These aspects are important for learning abstract and microscopic cell structure materials.

The student responses were consistent with the practicality test, which obtained an average of 88.6%. Positive responses to the media display, material, language, interactivity, and benefits indicate that the 3D digital learning media was well received and could support learning experiences through three-

dimensional visualization and targeted information presentation.

Thus, the CTML-based practicality results were supported by positive student responses. The average percentage of 88.88% indicates a very high level of practicality, showing that the developed media integrates three-dimensional visualization with information presentation that considers students' cognitive processing.

CONCLUSIONS

The 3D digital learning media was developed using eight CTML principles and was considered feasible based on expert validation and practical based on students' responses, with a practicality score of 88.88%. However, this study was limited to assessing the media's validity and practicality; students' conceptual understanding, learning outcomes, and cognitive load were not directly measured. Therefore, further research is needed to test the effectiveness of the media through direct assessments of conceptual understanding and learning outcomes.

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